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Exploring Forest Dynamics and Disturbances between 1990 and 2023 in Bago Yoma using Land Trendr Algorithm

Chan Myae Aung-2, Staff Officer, Forest Department
Maung Phyo, Range Officer, Forest Research Institute, Forest Department

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Exploring Forest Dynamics and Disturbances between 1990 and 2023 in Bago Yoma Using LandTrendr Algorithm

Chan Myae Aung-2, Staff Officer
Forest Department

Abstract

This study explores the spatial and temporal dynamics of forest disturbances in Bago Yoma, Myanmar, from 1990 to 2023, utilizing the LandTrendr algorithm with Landsat 5,7 and 8 satellite images. We analyze nine districts including Taungoo, Pyay, Tharawaddy, Bago, Yangon (North), Oaktaya, Datkhina, Magway and Thayet in Bago Yoma, identifying different disturbance types including shifting agriculture, dam construction, road development, plantation establishment, mining, settlements, rubber plantations, and other unclassified activities. The results showed that during the 33-year period, Bago Yoma lost 132,921.02 ha of total forest area, or approximately 6.5% of the initial forest cover (2,030,294.61 ha). The annual rate of deforestation in Bago Yoma for the 33-year period was approximately 4,027.91 ha (0.20%) of the initial forest cover lost annually. Shifting cultivation represents the largest disturbance type, impacting 112,876.47 ha, with 66,074.22 ha recovering to forested areas. Dam construction caused a substantial loss of natural forest, impacting 56,304.38 ha, followed by road construction (5,682.69 ha), settlement related disturbances (5,588.01 ha) and mining activities (42.57 ha) with no recovery recorded. Plantation establishment resulted in land conversion across 46,224.54 ha, with 33,450.57 ha stabilizing as established plantation areas. Rubber plantations covered 15,910.92 ha, with 12,451.5 ha stabilizing as sustained rubber plantation lands, signifying continued agricultural use. The accuracy assessment revealed an overall accuracy of 83.45%, validating the reliability of the LandTrendr. The findings highlight the necessity for specific interventions aimed at reducing shifting cultivation practices, especially in districts such as Taungoo, Pyay, and Tharawaddy, which have faced significant impacts. Restoration in watershed zones, particularly upstream of dams and reservoirs, should prioritize native species to stabilize soils. This study will provide baseline data of forest dynamics in Bago Yoma and support for forest managers to develop effective strategies to the specific challenges faced in each district.

Keywords: LandTrendr algorithm, Landsat, Bago Yoma, forest disturbances, deforestation

ပဲခူးရိုးမတွင် ၁၉၉၀ မှ ၂၀၂၃ ခုနှစ်အတွင်း သစ်တောများအပေါ် အနှောင့်အယှက်နှင့် သစ်တောများ၏ပြောင်းလဲခြင်းကို Land Trendr Algorithm ကို အသုံးပြု၍ လေ့လာဆန်းစစ်ခြင်း

ချမ်းမြေ့အောင်-၂၊ ဦးစီးအရာရှိ
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

ဤသုတေသနသည် ၁၉၉၀ ခုနှစ်မှ ၂၀၂၃ ခုနှစ်အတွင်း ပဲခူးရိုးမဒေသ၏ သစ်တောများ ပြောင်းလဲမှုကို Landsat 5၊ 7 နှင့် 8 ဂြိုဟ်တုဓာတ်ပုံများကို အသုံးပြု၍ LandTrendr algorithm နည်းလမ်းဖြင့် လေ့လာခဲ့ပါသည်။ ပဲခူးရိုးမတွင် ပါဝင်သည့် ခရိုင် ၉ ခု (တောင်ငူ၊ ပြည်၊ သာယာဝတီ၊ ပဲခူး၊ ရန်ကုန်(မြောက်)၊ ဥတ္တရ၊ ဒက္ခိဏ၊ မကွေးနှင့် သရက်ခရိုင်) တို့တွင် (၁)ရွှေ့ပြောင်းတောင်ယာ၊ (၂) ဆည်တည်ဆောက်မှု၊ (၃) လမ်းဖောက်လုပ်မှု၊ (၄) သစ်တော စိုက်ခင်းများတည်ထောင်ခြင်း၊ (၅) သတ္တုတူးဖော်မှု၊ (၆) မြို့ပြတည်ဆောက်မှုများ၊ (၇) ရာဘာ စိုက်ခင်းများတည်ထောင်ခြင်းနှင့် (၈) အခြားကိစ္စရပ်များအပါအဝင် သစ်တောများအပေါ် အနှောင့်အယှက် (Forest disturbances) အမျိုးအစား ရှစ်ခုခွဲခြား၍ လေ့လာဆန်းစစ်ခဲ့ပါသည်။ ၃၃ နှစ်ကာလအတွင်း သစ်တောဧရိယာ ၂,၀၃၀,၂၉၄.၆၁ ဟက်တာမှ ၁၃၂,၉၂၁.၀၂ ဟက်တာအဖြစ် (၆.၅ %) ဆုံးရှုံးခဲ့ပြီး၊ နှစ်စဉ် သစ်တော ဧရိယာ ၄,၀၂၇.၉၁ ဟက်တာ (၀.၂၀%) နှုန်းဖြင့် ပြုန်းတီးလာခဲ့ပါသည်။ သစ်တော များအပေါ် အကြီးမားဆုံးအနှောင့်အယှက်မှာရွှေ့ပြောင်းတောင်ယာစိုက်ပျိုးခြင်းဖြစ်ပြီး ယင်းကြောင့် သစ်တော ဧရိယာ ၁၁၂,၈၇၆.၄၇ ဟက်တာ ဆုံးရှုံးခဲ့ရပါသည်။ အခြား တစ်ဖက်တွင်လည်း ရွှေ့ပြောင်း တောင်ယာ စိုက်ပျိုးသည့် နေရာများမှ သစ်တောအဖြစ်သို့ ၆၆,၀၇၄.၂၂ ဟက်တာ ပြန်လည်ဖြစ်ထွန်း လာကြောင်း တွေ့ရှိရပါသည်။ သစ်တောများအပေါ် ဒုတိယအကြီးမားဆုံး အနှောင့်အယှက်မှာ ဆည် တည်ဆောက်မှုဖြစ်ပြီး သစ်တောဧရိယာ ၅၆,၃၀၄.၃၈ ဟက်တာ ဆုံးရှုံးခဲ့ရပါသည်။ တတိယ အကြီးမားဆုံး အနှောင့်အယှက်မှာ လမ်းဖောက်လုပ်မှုဖြစ်ပြီး သစ်တောဧရိယာ၅,၆၈၂.၆၉ ဟက်တာ ဆုံးရှုံးခဲ့ပါသည်။ ၃၃ နှစ်ကာလအတွင်း မြို့ပြလူနေ ဧရိယာများ ချဲ့ထွင် ခြင်းကြောင့် ၅,၅၈၈.၀၁ ဟက်တာနှင့် သတ္တုတူးဖော်မှုကြောင့် ၄၂.၅၇ ဟက်တာ အသီးသီး ဆုံးရှုံးခဲ့ပါသည်။ စိုက်ခင်းများ တည်ထောင်မှုကြောင့် သစ်တောဧရိယာ ၄၆,၂၂၄.၅၄ ဟက်တာသည် အခြားမြေ အသုံး ချမှုပုံစံမျိုး အဖြစ်သို့ ပြောင်းလဲသွားခဲ့သော်လည်း ၎င်းဧရိယာအနက် ၃၃,၄၅၀.၅၇ ဟက်တာသည် အောင်မြင် သော သစ်တောစိုက်ခင်းများအဖြစ်သို့ ပြန်လည်ကူးပြောင်းလာကြောင်း တွေ့ရှိရပါသည်။ ရာဘာ စိုက်ခင်းများသည် သစ်တောဧရိယာ ၁၅,၉၁၀.၉၂ ဟက်တာကို နေရာယူခဲ့ပြီး ယင်းတို့အနက် ၁၂,၄၅၁.၅ ဟက်တာသည် အမြဲတမ်း ရာဘာစိုက်ခင်းများအဖြစ် တည်မြဲလျက်ရှိကြောင်း တွေ့ရှိ ရပါသည်။ ယခုသုတေသနတွင် LandTrendr algorithm ကို အသုံးပြု၍ ခွဲခြားခဲ့သည့် ရလဒ်များ အပေါ် မှန်ကန်တိကျမှု စစ်ဆေးခြင်း (accuracy assessment) မှာ ၈၃.၄၅ % ရှိပါသည်။ ယခုသုတေ သန၏ လေ့လာတွေ့ရှိချက်များအရ တောင်ငူ၊ ပြည်နှင့် သာယာဝတီခရိုင်များတွင် ရွှေ့ပြောင်း တောင်ယာစနစ်ကို လျှော့ချရန် အထူးလိုအပ်ပါကြောင်း အကြံပြုလိုပါသည်။ ထို့အပြင် ခရိုင် အချို့

တွင် တည်ဆောက်ခဲ့သောဆည်များ၏ အထက်ပိုင်းရှိ ရေဝေရေလဲ ဧရိယာများတွင် မြေဆီလွှာ ထိန်းသိမ်းခြင်းလုပ်ငန်းများနှင့်အတူ သစ်တောများ ပြန်လည် ထူထောင်ရေးလုပ်ငန်းများ စဉ်ဆက် မပြတ် ဆောင်ရွက်သွားရန် လိုအပ်ပါသည်။ ဤ သုတေသန၏ လေ့လာ တွေ့ရှိချက်များသည် ၁၉၉၀ ခုနှစ် မှ ၂၀၂၃ ခုနှစ်အထိ၊ (၃၃) နှစ်တာ ကာလအတွင်း ပဲခူးရိုးမ သစ်တောများ ပြောင်းလဲလာခြင်းနှင့် စပ်လျဉ်းသည့် အခြေခံအကြောင်းအရာများကို ဖော်ထုတ်ပေးပြီး သစ်တောစီမံအုပ်ချုပ်သူများ အနေ ဖြင့် ပဲခူးရိုးမရှိ ခရိုင်တစ်ခုချင်းစီတွင် ကြုံတွေ့နေရသည့် စိန်ခေါ်မှုများအတွက် ထိရောက်သော သစ်တော စီမံအုပ်ချုပ်မှု နည်းလမ်းများ ချမှတ် ဆောင်ရွက် သွားနိုင်ရေး ကူညီပံ့ပိုးပေးနိုင်မည် ဖြစ်ပါ သည်။

Exploring Forest Dynamics and Disturbances between 1990 and 2023 in Bago Yoma using LandTrendr Algorithm

1. Introduction

Tropical forests exhibit significant species diversity and serve as crucial global carbon sinks, mitigating greenhouse gas emissions and alleviating climate change (Pan et al., 2011). The loss and degradation of tropical forests result in significant carbon emissions into the atmosphere, impacting the global carbon cycle and regional climate fluctuations. Myanmar possesses the second-largest land area in Southeast Asia, with forest coverage declining from 57.9% in 1990 to 46.96% in 2010 and further to 42.19% in 2020 (FAO, 2020). The patterns of deforestation in Myanmar differ by area, but they are primarily associated with the expansion of large-scale agricultural plantations, clear-cutting, selective logging, and shifting cultivation practices (Naing Tun et al., 2021).

Bago Yoma, recognized as the prominent natural teak-bearing forest, is situated in the central part of lowland Myanmar. The common forest type in Bago Yoma is mixed deciduous forest, characterized by a diverse array of tree species mixed with extensive bamboos. Teak (*Tectona grandis*) accompanied by other commercially significant hardwoods including pyinkado (*Xylia xylocarpa*), padauk (*Pterocarpus macrocarpus*), taukkyan (*Terminalia tomentosa*), and various *Dipterocarpus* species (Khai et al., 2016; Mon et al., 2010; Shimizu et al., 2017) are dominant in the area. Teak is the most harvested tree species in the region due to local and regional demand for its high-quality timber.

The primary drivers of deforestation and forest degradation in Myanmar include logging, mining, and agricultural expansion (Mon et al., 2010; Naing Tun et al., 2021). These activities threaten forests across the nation, particularly in ecologically, socially, and economically important areas such as the Bago Yoma region (Mon et al., 2010). The Bago Yoma forests have a long history of timber production under the Myanmar Selection System (MSS), which remains the most enduring forest management practice in the region (Saung et al., 2021). Besides timber production, these forests support local livelihoods by providing non-timber forest products (NTFPs) and arable land for agricultural activities. However, overexploitation has significantly impacted the forest ecosystem over time, resulting in observable changes in forest health and productivity.

Understanding forest disturbances and the agents driving land-use changes is critical for ensuring the sustainable management of forests (Kennedy et al., 2010; Kennedy et al., 2012; Vogeler et al., 2020). Identifying patterns and causes of deforestation will provide valuable insights for developing effective management strategies to protect and restore forest ecosystems.

Remote sensing technology has proven to be an effective tool for monitoring forest disturbances and analyzing forest dynamics (Cohen et al., 2016; Hansen & Loveland, 2012). By utilizing satellite imagery across temporal scales, researchers can retrospectively analyze historical disturbances and gain insights into the causes and consequences of forest changes (Wulder et al., 2008). This technology enables a better understanding of forest ecosystems, contributing to the formulation of data-driven approaches for forest conservation and sustainable management.

Addressing deforestation and forest degradation in Myanmar will require an integrated approach that incorporates remote sensing analysis, sustainable forest management practices, and a comprehensive understanding of the socio-economic factors driving forest exploitation. By bridging the knowledge gap on deforestation patterns and their root causes, Myanmar can enhance its forest management strategies and contribute to global efforts in conserving biodiversity and mitigating climate change.

The application of remote sensing technology, particularly the use of Landsat satellite imagery across temporal scales, allows for a deeper understanding of the drivers of change and forest disturbances affecting the Bago Yoma forests. By identifying the primary forces contributing to these disturbances and analyzing their spatio-temporal dynamics-changes in location and intensity over time-this research aims to provide critical insights into the sustainable conservation of the Bago Yoma forest's ecosystems. Additionally, the study seeks to support the development of effective forest management and governance strategies, ensuring the long-term preservation and resilience of these vital ecosystems.

2. Objectives

The main objectives of this study are:

(1) To analyze forest disturbance patterns and recovery trajectories from 1990 to 2023 using time-series change detection methods and to establish a Forest Dynamics Database for the Bago Yoma region, documenting year-by-year forest changes, and
(2) To identify and analyze the causal agents contributing to forest disturbances in the Bago Yoma region.

3. Materials and Methods

3.1 Study area

The study area, Bago Yoma is a significant forested region identified using the 1990 land cover map generated by Servior Mekong (Figure 1). The total forest cover in this area was calculated as 2,030,294.61 ha (Flores et al., 2018) serving as the baseline for analyzing forest disturbances and recovery dynamics over the 33-year study period. This extensive forest cover makes Bago Yoma a critical site for understanding patterns of anthropogenic and natural impacts on forest ecosystems and their subsequent recovery trajectories. Study area includes (9) districts namely (1) Taungnoo, (2) Bago, (3) Pyay, (4) Tharawady, (5) Ottaya, (6) Dekkhina, (7) Magway, (7) Thayet and (8) North Yangon districts.

3.2 Data sources

Landsat satellite images were used to analyze changes in forest dynamics and disturbances.

The datasets are:

- Landsat 5 TM: For the years 1990 to 2011.
- Landsat 8 OLI: For the years 2013 to 2023.
- Landsat 7 ETM+: Utilized only from 2000 to 2002 due to the scan line error that restricts its use beyond this timeframe(Hossain et al., 2015).

The analysis of detecting forest disturbances was conducted from November to January each year to account for the seasonal characteristics of the region and ensure accurate detection of forest dynamics and disturbances. This time frame was selected specifically to avoid the impact of seasonal variations that can influence the findings. The time following January signifies the beginning of the dry summer season, characterized by a substantial fall of leaves as a part of the region's natural phenological cycle. The use of imagery from the rainy season was avoided due to the limitations it imposes on accurate detection of forest disturbances and recovery patterns. Moreover, persistent cloud cover during the rainy season increases the likelihood of interference in the imagery, which can lead to misclassification and reduced reliability of the results. To ensure the most accurate analysis of forest dynamics and disturbances and to maintain high data quality, imagery acquisition was prioritized during cloud-free conditions from November to January.

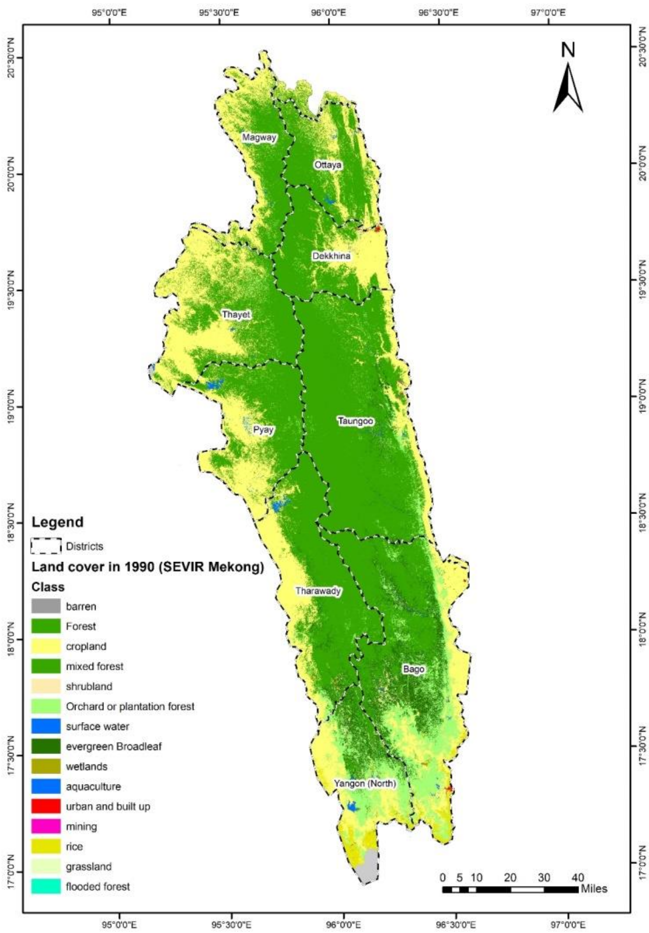

Figure 1: Bago Yoma Area (source: Sevir Mekong, 1990)

The LandTrendr algorithm, which stands for Landsat-based Detection of Trends in Disturbance and Recovery, is a spectral-temporal segmentation method intended for identifying changes in time series data derived from medium-resolution satellite images, mainly from the Landsat series(Cohen et al., 2018). The LandTrendr algorithm captures both abrupt events (like forest removal) and gradual processes (like forest recover) using spectral indices as a function of time(Wang et al., 2022). The Normalised Burn Ratio (NBR) and Normalised Difference Vegetation Index (NDVI) are used for monitoring forest disturbances(Guo et al., 2022). The Normalised Burn Ratio Index (NBR) can be used to detect forest fires and disturbances(Van Wagtendonk et al., 2004). The Normalized Difference Vegetation Index (NDVI) is a widely used for quantifying the greenness and leaf density of the vegetation canopy, thereby enabling the characterization of vegetation growth (Peng et al., 2019). The NBR and NDVI indices were used to identify the forest disturbance data for Bago Yoma.

$$\mathrm{NBR} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}}$$

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

Where, NIR is near-infrared band, SWIR is short-wave infrared band, RED is the red band.

The LandTrendr algorithm includes a total of nine parameters, with eight control parameters designed to fine-tune the spectro-temporal segmentation process and the annual image collection. For this study, the parameter settings were as follows: maximum segments were set to 6, spike threshold to 0.9, vertex count overshoot to 3, prevent one year recovery was enabled (true), recovery threshold was 0.25, p-value threshold was 0.05, best model proportion was 0.75, and minimum observations needed was 6. The present study does not categorize land cover into specific kinds, such as closed forest, open forest, or other wooded land, etc. We focused on the aggregate disturbed areas caused by diverse anthropogenic activities. Eight disturbance types (i.e. shifting cultivation, construction of dam, construction of road, plantation, mining, settlements, rubber plantation, others) and their forest recovery from disturbances were identified and mapped using the LandTrendr algorithm.

Table 1: Descriptions of Disturbance Types

No.	Disturbance type	Description
1	Shifting cultivation	Areas where traditional farming methods include burning trees, clearing forests on frequently, and growing crops for a short time before allowing the land recover
2	Dam construction	Areas in which forest were cut down for the construction of reservoirs, dams, or other water infrastructure
3	Road construction	Areas where forests were disturbed with linear clearings to develop roads, highways, or other transportation networks
4	Plantation	Areas where forests were converted for large-scale cultivation of commercial timber species
5	Mining	Areas showing significant forests removal due to mining activities, often resulting in exposed soil, pits, or altered landscapes
6	Settlement	Areas where forests were transformed into built-up areas, including human habitation, infrastructure, and urban development
7	Rubber Plantation	Areas specifically developed for the cultivation of rubber trees
8	Others	Disturbance areas that were unable to be accurately identified as a result of confusing satellite signatures or limited ground validation. This class serves as a placeholder for all uncertain disturbances and do not fall within the established categories

3.3 Accuracy Assessment

Accuracy assessment was carried out by employing simple random sampling method to assess the forest disturbance results. High resolution Google Earth images and field photos, ground truth points, completed by 30 m resolution false color composite images of Landsat 5,7 and 8 satellite images were used as reference dataset in accuracy assessment of the classification results.

4. Results

4.1 Overall disturbances in Bago Yoma between 1990 and 2023

Arcgis pro software was used to generate 731 total random training samples for accuracy evaluation (Table 2). The overall accuracy of forest disturbance classification results is 83.45%.

Table 2: Confusion matrix for forest disturbances

	Reference			
	Disturbed	Not Disturbed	Total	User's accuracy (%)
Disturbed	147	60	207	71.01
Not Disturbed	61	463	524	88.36
Total	208	523	731	
Producer's accuracy (%)	70.67	88.53		

Overall accuracy =83.45%

Bago Yoma's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 2). This data aggregates the yearly disturbances of shifting cultivation, dam construction, road construction, plantation establishment, mining, settlement development, rubber and others disturbances. The total disturbed area across all categories is 248,469.5 ha, with 115,548.48 ha indicating signs of recovery. According to the present study, Bago Yoma experienced a total forest area loss of 132,921.02 ha over the 33-year period from 1990 to 2023, which is equivalent to approximately 6.5% of the initial forest cover, 2,030,294.61 ha by Servir Mekong serving as a baseline data for analyzing forest disturbances and recovery patterns.

The annual rate of deforestation in Bago Yoma for the 33-year period from 1990 to 2023 was approximately 4,027.91 ha (0.20%) of the initial forest cover lost annually.

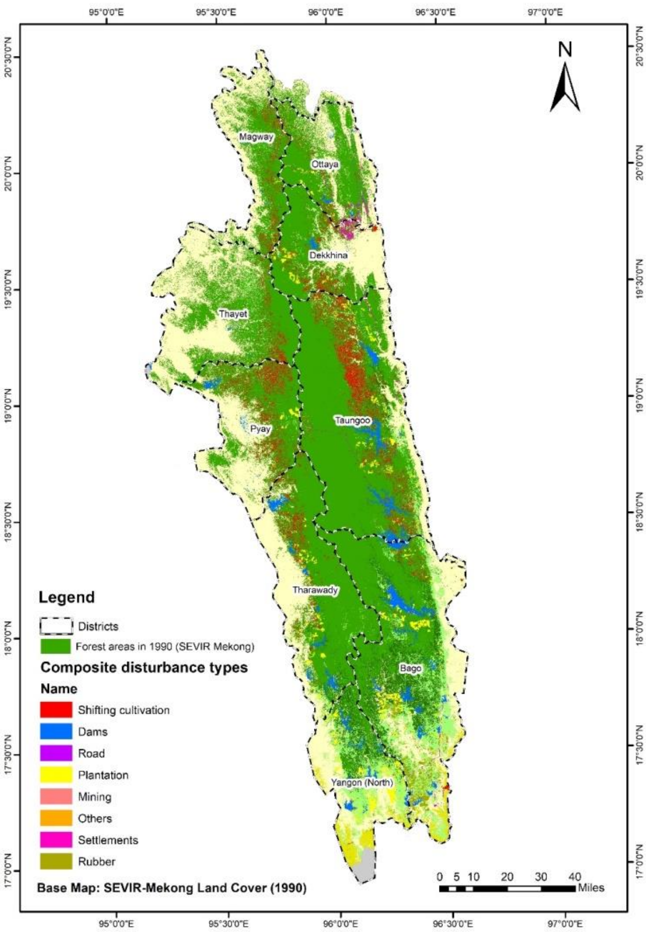

Figure 2: Distribution of composite disturbance area in Bago Yoma (1990-2023)

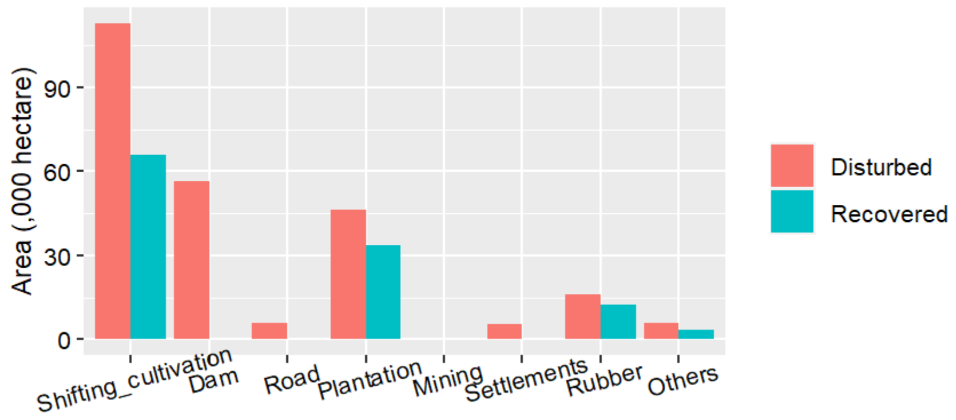

Figure 3: Total disturbed and recovered area in Bago Yoma (1990-2023)

Shifting cultivation represents the largest disturbance type, impacting 112,876.47 ha, with 66,074.22 ha recovering to forested areas (Figure 3). Shifting cultivation has been the primary cause of forest loss, resulting in a net loss of 46,802.25 ha of forest land. Dam construction caused a substantial loss of natural land, covering 56,304.38 ha, with no recovery recorded as these areas were permanently transformed for infrastructure. Road construction disturbed 5,682.69 ha, also showing no recovery due to the permanent nature of these developments.

Plantation establishment resulted in land conversion across 46,224.54 ha, with 33,450.57 ha stabilizing as established plantation areas. Mining activities affected 42.57 ha, without recovery, as mining sites tend to remain permanently changed (Figure 3).

The "Others" category, which includes disturbances not categorized due to limited ground validation, accounted for 5,839.92 ha, with 3,572.19 ha indicating forest recovery (Figure 3). Settlement related disturbances impacted 5,588.01 ha, with no recovery as these areas were permanently urbanized. Rubber plantations covered 15,910.92 ha, with 12,451.5 ha stabilizing as sustained rubber plantation lands, signifying continued agricultural use.

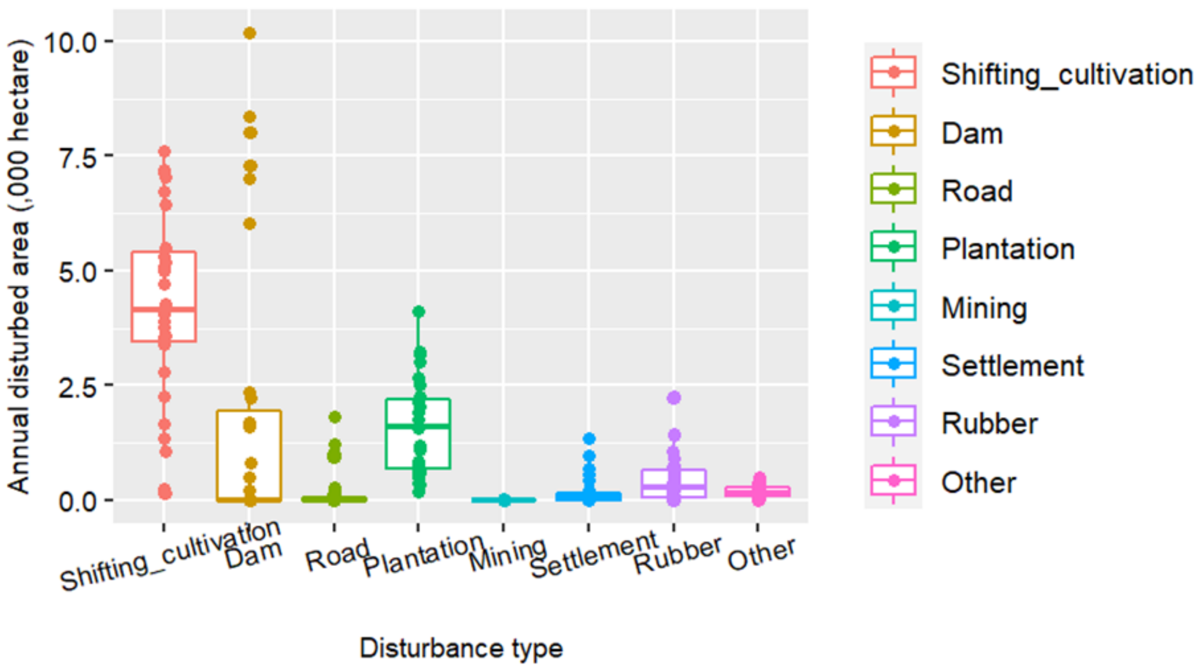

Figure 4: Annual disturbed area of each disturbance type in Bago Yoma (1990-2023)

Table 3: Descriptive statistics of annual disturbed area (,000 hectare)

No.	Category	mean	max	min	sd	IQR
1	Shifting cultivation	4.30	7.60	0	2.05	1.92
2	Dam	1.82	10.2	0	3.11	1.95
3	Road	0.183	1.81	0	0.438	0.0588
4	Plantation	1.58	4.10	0	1.01	1.51
5	Mining	0.00137	0.0426	0	0.00765	0
6	Settlement	0.180	1.36	0	0.317	0.136
7	Rubber	0.506	2.25	0	0.609	0.590
8	Other	0.185	0.510	0	0.139	0.184

Shifting cultivation is the most significant source of forest disturbance throughout the research period (Figure 3, 4 and Table 3). With a mean disturbed area of 4,300 ha, it shows significant variability over time, as shown by a standard deviation of 2,050 ha and an interquartile range (IQR) of 1.92 (Table 3). This indicates that shifting cultivation remains to have a significant influence, with certain years exhibiting particularly high levels of disturbance, peaks at 7,600 ha (Table 3). The IQR represents the range within which the middle 50% of the data points fall.

$$\text{IQR} = \text{Q3} - \text{Q1}$$

$$\text{Q1} = \text{Mean} - \frac{\text{IQR}}{2} = 4.30 - \frac{1.92}{2} = 4.30 - 0.96 = 3.34$$

$$\text{Q3} = \text{Mean} + \frac{\text{IQR}}{2} = 4.30 + \frac{1.92}{2} = 4.30 + 0.96 = 5.26$$

$$\text{IQR} = 5.26 - 3.34 = 1.92$$

Therefore, the interquartile range for shifting cultivation disturbances indicates that the middle 50% of the data points falls between approximately 3,340 and 5,260 ha.

Construction of dams also contributes moderately to forest disturbance, though the effects tend to be more sporadic. The mean area affected by dams is 1,820 ha, with a maximum value of 10,200 ha. The standard deviation of 3,110, together with an interquartile range of 1.95, indicates the variability in dam-related disturbances (Table 3).

$$\text{Q1} = \text{Mean} - \frac{\text{IQR}}{2} = 1.82 - \frac{1.95}{2} = 1.82 - 0.975 = 0.845$$

$$\text{Q3} = \text{Mean} + \frac{\text{IQR}}{2} = 1.82 + \frac{1.95}{2} = 1.82 + 0.975 = 2.795$$

$$\text{IQR} = 2.795 - 0.845 = 1.95$$

Therefore, the interquartile range for dam construction disturbances indicates that the middle 50% of the data points falls between approximately 845 and 2,795 ha.

Plantations represent a significant source of forest change, exhibiting a relatively consistent impact over time. The mean area resulting from plantations is 1,580 ha, with a standard deviation of 1,010 ha, maximum value of 4,100 thousand hectares and an interquartile range of 1.51. These statistics indicate that plantations have a moderate influence on forest areas.

$Q1 = \text{Mean} - \frac{\text{IQR}}{2} = 1.58 - \frac{1.51}{2} = 1.58 – 0.755 = 0.825$

$Q3 = \text{Mean} + \frac{\text{IQR}}{2} = 1.58 + \frac{1.51}{2} = 1.58 + 0.755 = 2.335$

$\text{IQR} = 2.335 – 0.825 = 1.51$

Therefore, the interquartile range for plantations indicates that the middle 50% of the data points falls between approximately 825 and 2,335 ha.

Rubber plantations, although exhibiting a lesser degree of impact in comparison to shifting cultivation and plantations, still contribute noticeably to forest disturbance. The mean disturbed area is 506 ha, with a standard deviation of 609 ha, maximum value of 2,250 ha and an IQR of 0.590 thousand hectares.

$Q1 = \text{Mean} - \frac{\text{IQR}}{2} = 0.506 - \frac{0.590}{2} = 0.506 – 0.295 = 0.211$

$Q3 = \text{Mean} + \frac{\text{IQR}}{2} = 0.506 + \frac{0.590}{2} = 0.506 + 0.295 = 0.801$

$\text{IQR} = 0.801 – 0.211 = 0.59$

Therefore, the interquartile range for rubber plantations indicates that the middle 50% of the data points falls between approximately 211 and 801 ha.

Roads represent a minimal forest disturbance overall, as evidenced by a mean disturbed area of 183 ha, a standard deviation of 438ha, maximum disturbed area of 1,810 ha and an IQR of 0.0588.

$Q1 = \text{Mean} - \frac{\text{IQR}}{2} = 0.183 - \frac{0.0588}{2} = 0.183 – 0.0294 = 0.1536$

$Q3 = \text{Mean} + \frac{\text{IQR}}{2} = 0.183 + \frac{0.0588}{2} = 0.183 + 0.0294 = 0.2124$

$\text{IQR} = 0.2124 – 0.1536 = 0.0588$

Therefore, the interquartile range for roads indicates that the middle 50% of the data points falls between approximately 153.6 and 212.4 ha.

Likewise, settlements have a negligible impact on forest areas, with a mean disturbed area of 180 ha, a standard deviation of 317 ha, maximum value of 1,360 ha and an interquartile range of 0.136.

$Q1 = \text{Mean} - \frac{\text{IQR}}{2} = 0.180 - \frac{0.136}{2} = 0.180 – 0.068 = 0.112$

$Q3 = \text{Mean} + \frac{\text{IQR}}{2} = 0.180 + \frac{0.136}{2} = 0.180 + 0.068 = 0.248$

$\text{IQR} = 0.248 – 0.112 = 0.136$

Therefore, the interquartile range for settlements indicates that the middle 50% of the data points falls between approximately 112 and 248 ha.

Disturbances categorized as "Other" have a small but consistent impact, with a mean disturbed area of 185 ha, a standard deviation of 139 ha, a maximum value of 510 ha and an IQR of 0.184. These activities do not vary much year-to-year, indicating their limited role in forest disturbance. In contrast, mining has the least impact on forest areas, with a negligible mean disturbed area of 1.37 ha, a standard deviation of 7.65, a maximum value of 42.6 ha and an IQR of 0. This suggests that mining activities have not been a significant driver of forest disturbance in Bago Yoma.

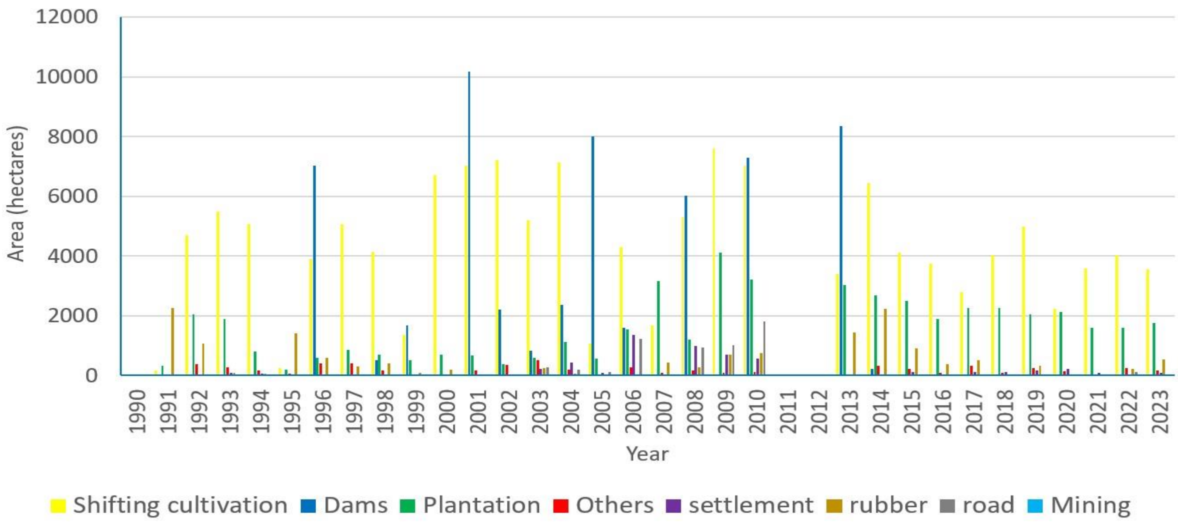

Figure 5: Temporal distribution of disturbed area in Bago Yoma (1990-2023)

4.2 Disturbances in Taungnoo District between 1990 and 2023

Taungnoo district's composite disturbance map shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 6). This map aggregates the yearly disturbances of shifting cultivation, dam construction, road construction, plantations, and others into a single dataset. Each disturbance category indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

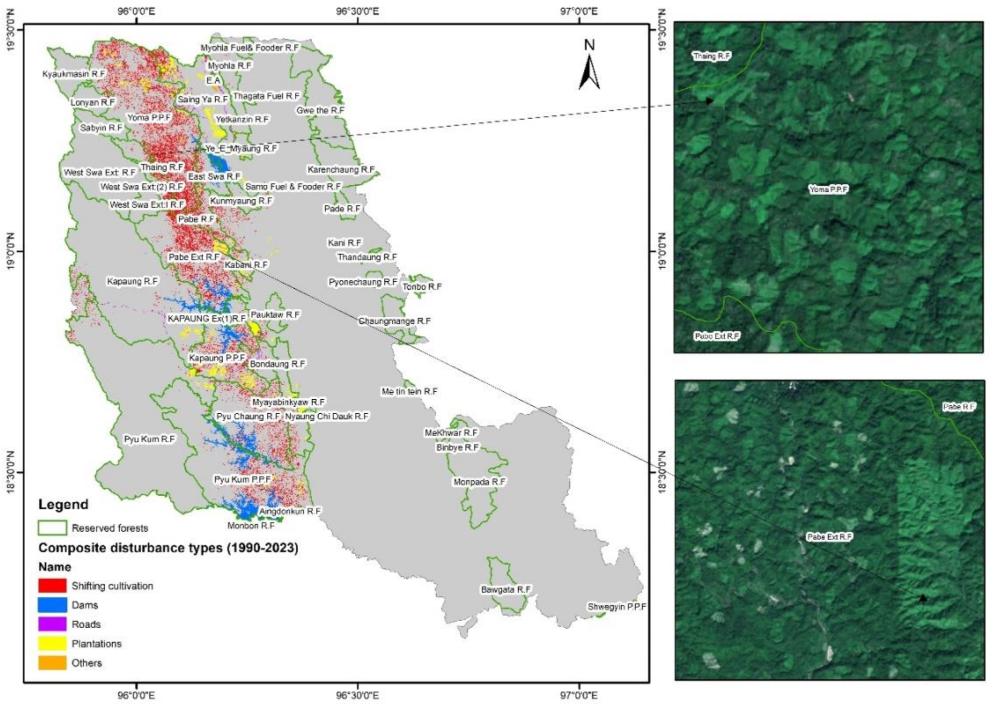

Figure 6: Distribution of composite disturbance area in Taungoo District (1990-2023)

The Taungnoo district's analysis of disturbed and recovered areas on composite data over a 33-year period (1992–2023) reveals the extent of forest area changes across various disturbance types. During the study period, disturbances occurred over 42,165 ha, with shifting cultivation having the most significant impact. The recovery of 28,494.36 ha was observed, as some of these disturbed shifting cultivation lands transitioned back to forest over time.

Dam construction disturbances occurred across 17,799.03 ha, the second-largest impacted area. However, no recovery was observed, indicating the permanent transformation of these areas into infrastructure and reservoirs. The overall area affected by road construction was 1,509.57 hectares, which is significant permanent disturbed areas. 8,805.51 ha of plantation establishment were captured over the study period, with recovery observed in 5,741.37 ha, indicating that some plantation areas transitioned back to forest. Of all the categories, the "Others" category had the least affected area, with disruptions occurring across 496.62 hectares. Recovery occurred on 309.69 ha, indicating modest but significant shifts towards stable forest.

The overall disturbed area across all categories was 70,775.73 ha, including all sites where disturbances occurred throughout the study period. Of this, 34,545.42 ha (about 49.5%) indicated signs of recovery, showing natural or managed regrowth in certain disturbance types.

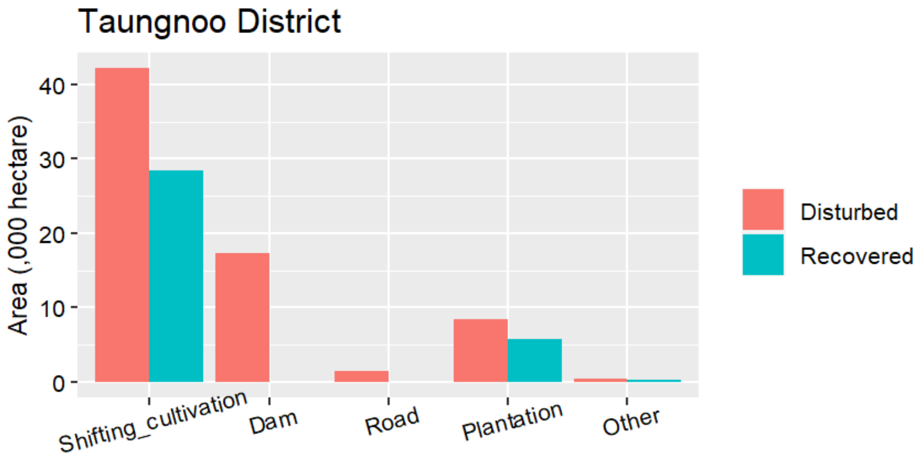

Figure 7: Total disturbed and recovered area in Taungnoo District

In the 33-year period (1990–2023), the analysis of yearly disturbance types in Taungoo district revealed significant temporal variation (Figure 8). During the study period, shifting cultivation was the most prominent disturbance type, while its extent fluctuated frequently. Peak disturbances of shifting cultivation were observed in 2000 (4,043.79 ha), 2003 (3210.48 ha), and 2009 (4,406.22 ha). In 2023, the extent of shifting cultivation was estimated at only 605.52 ha, a continuous decline that began in 2021.

Dam construction became a significant disturbance type in 2001, affecting a total area of 2,837.16 ha, primarily due to the construction of the Swa Chaung Dam. The most significant dam-related disturbance occurred in 2008, impacting an area of 5,661.18 hectares, primarily due to the construction of the Kabaung Reservoir. Earlier, in 2006, construction of the Kung Chaung Reservoir began, impacting 391.86 ha, with disturbances increasing to 4,172.94 ha in 2010 as the reservoir expanded. In 2013, the Phyu Chaung Reservoir was identified as contributing to a disturbance area of 4,735.89 ha. This finding depended on the availability of satellite data, as the analysis of disturbances during 2011 and 2012 was limited due to the lack of data for those years.

Disturbances due to roads were first detected in 2006, affecting 250.47 hectares. The highest extent of these disturbances was identified in 2009 at 570.6 ha, with 310.14 ha and 378.36 ha recorded in 2008 and 2010, respectively. Throughout the study period, the establishment of plantations exhibited steady growth, with significant peak in 2009 (1,176.84 ha) and 2010 (1,011.06 ha).

The Others category, which includes unclassified disturbances, exhibited rare activity during the study period. In 2003, disturbances were detected at 110.97 hectares, with the highest degree of disturbance occurring in 2006 (158.4 ha) and 2008 (166.95 ha). In 2009, a subsequent decline was observed, resulting in a decrease of the disturbed area to 60.3 ha.

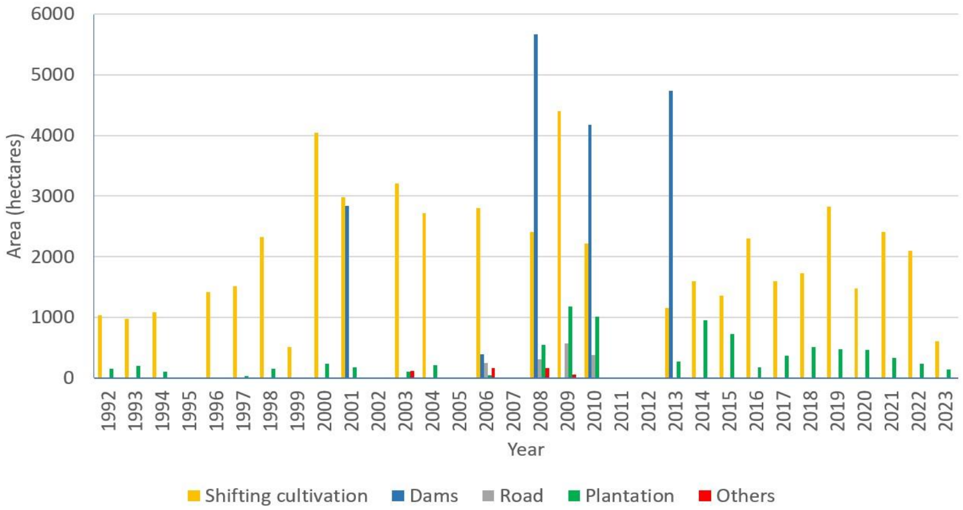

Figure 8: Temporal distribution of disturbed area in Taungnoo District

4.3 Disturbances in Bago District between 1990 and 2023

Bago district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023). This data aggregates the yearly disturbances of shifting cultivation, dam construction, road construction, plantations, mining, settlements, rubbers and others into a single dataset. Each disturbance type indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

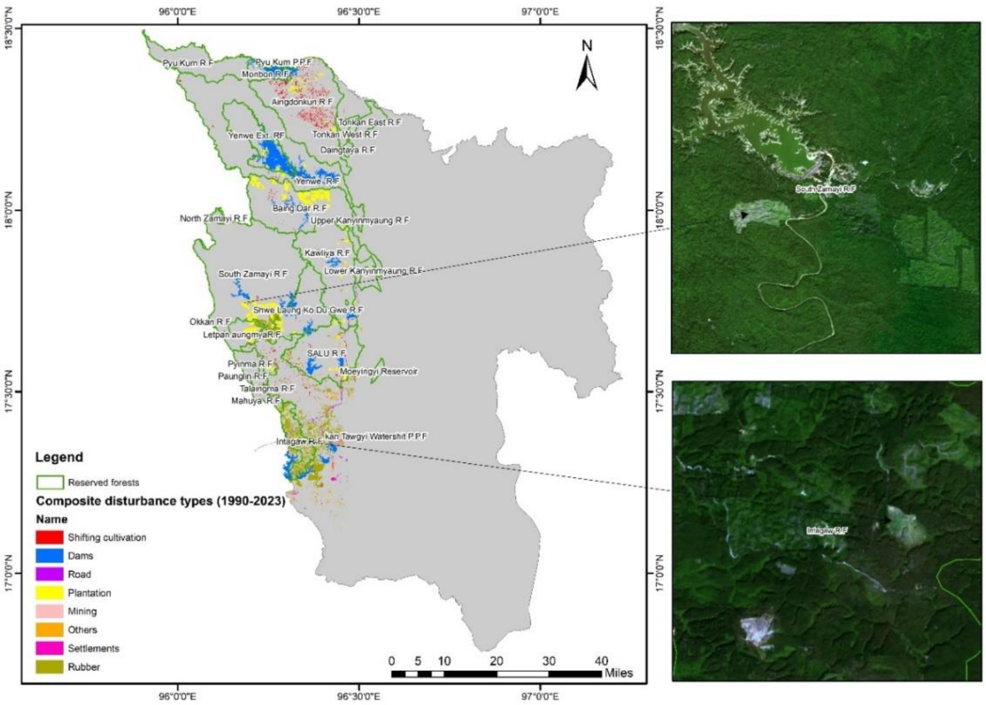

Figure 9: Spatial-temporal distribution of disturbance area in Bago District

The total disturbed area across all categories is 58,715.66 ha, with 25,236.27 ha indicating signs of recovery (Figure 10). During the period of 33 years, shifting cultivation caused 4,842.09 ha of disturbed land, with 3,212.73 ha indicating recovery into forested areas. Similarly, 1,263.06 ha of the 1,873.35 ha in the "Others" category transitioned to vegetation cover. In addition, plantations affected 1,2081.06 ha, with 8,397.99 ha recovered areas. Rubber plantations impacted 15,761.34 ha, with 12,362.49 ha stabilizing as sustained rubber plantation lands, indicating their continuing use for agricultural output instead of returning to forests. Conversely, construction of dams resulted in the most significant permanent disturbance, impacting 2,2356.56 ha, with no recovery observed, since these areas are permanently transformed into water related infrastructure. Road construction affected 1,298.25 ha, while settlements disrupted 457.56 ha, both signifying irreversible changes to the land with no chance for natural recovery.

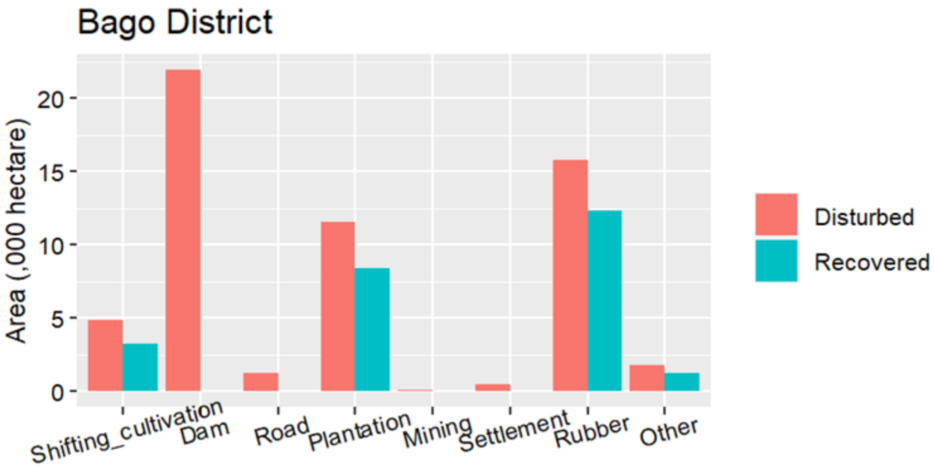

Figure 10: Total disturbed and recovered area of Bago District

The analysis of yearly disturbance types in Bago district over 33 years (1991–2023) reveals significant spatiotemporal variations in forest cover changes, with contributions from multiple disturbance types, including shifting cultivation, dams, plantations, others, settlements, rubber, roads, and mining. The analysis of shifting cultivation in Bago district from 1991 to 2023 demonstrates the seasonal and local nature of this land-use practice, as evidenced by the dynamic fluctuations in the extent of disturbed areas. In the initial years, disturbances fluctuated, with significant maximum in 1991 (168.66 ha), 1995 (255.33 ha), 1998 (300.06 ha) and 2000 (281.43 ha) (Figure 11). During the period from 2001 to 2010, disturbance levels were modest, reaching a maximum of 310.95 ha in 2003 and 217.35 ha in 2004. Later years of this time frame, such as 2007 and 2008, had lower levels of disturbance, with 85.32 ha and 81.81 ha respectively. In recent years, there has been an increase of shifting cultivation, with significant peaks observed in 2019 at 382.59 ha and the highest disturbance recorded in 2023 at 755.82 ha.

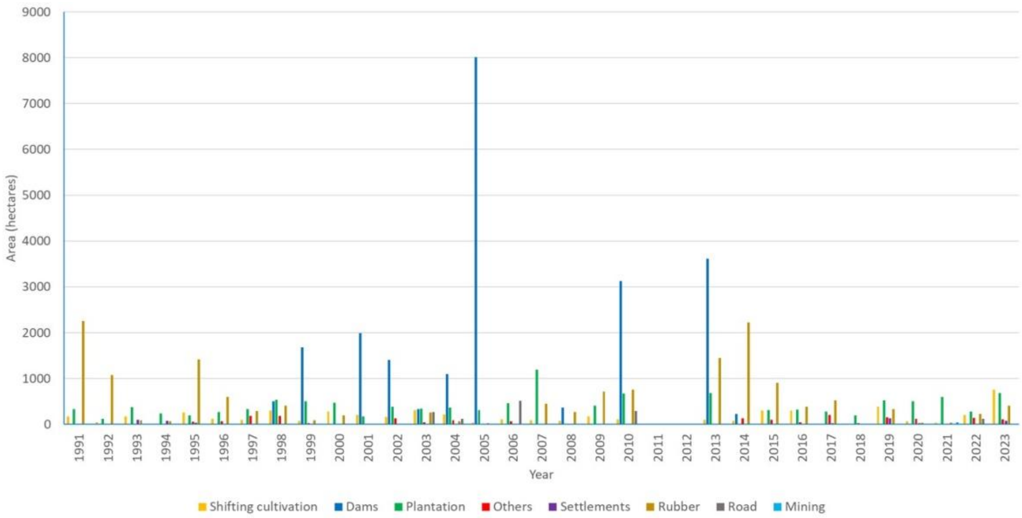

Figure 11: Temporal distribution of disturbed area in Bago District

Between 1998 and 2013, dam construction activities had a considerable impact on the forest areas in Bago district, with multiple dams being built, extended, or started during this time. The establishment of the Za Le Taw dam in 1998 initiated significant disruptions, impacting 505.89 ha of forest areas. In 1999, the Ma Zin, Zaung Tu, and Baw Ni dams together affected 1,684.62 ha, representing a major expansion in dam infrastructure. By 2001, the Baing Da Dam was constructed, contributing 1,993.32 ha that disturbed forest areas. The construction of the Kawliya and Alaing Ni dams and the extension of the Baing Da dam in 2002 caused a total disturbance of 1,408.23 ha. Subsequent extensions of the Baing Da dam in 2003 increased the affected area by 330.39 ha. The Kawliya dam was extended, and the construction of the Ye Nwe dam began in 2004, impacting an area of 1,093.23 ha. In 2005, the Ye Nwe dam was significantly extended, leading to the most considerable single-year disruption, impacting 8,009.03 ha of forest areas. The Kun Chaung dam was constructed in 2010, affecting an area of 3,129.39 ha. By 2013, the Salu dam and a few small dams were built, affecting a total area of 3,612.69 ha.

The growth of plantations in Bago district from 1990 to 2023 showed dynamic fluctuations in the extent of forest areas converted for plantations, reflecting varying levels of expansion over the years. From 1991 to 1999, plantation establishment ranged from 119.79 hectares in 1992 to a peak of 534.78 ha in 1998 and 506.97 ha in 1999, signifying the beginning years of plantations. The following years from 2000 to 2009 had steady plantation establishment, marked by major increases in 2003 (345.96 ha), 2006 (462.78 ha), and a substantial peak in 2007 at 1,196.46 ha, the highest single-year expansion recorded in the study period. From 2010 to 2023, plantation growth with notable, peaks in 2013 (683.73 ha), 2019 (519.84 ha), 2021(595.26 ha) and the largest expansion in 2023 reaching to 686.88 ha.

Early disturbances in “Others” category were minimal, with the first recorded disturbance areas in 1995 (52.65 ha) and a gradual increase to 181.26 ha in 1998. This was followed by a decline in the following years, with occasional peaks, such as 132.3 ha in 2002 and 84.69 ha in 2004. Significant activity started over in subsequent years, including 127.8 ha in 2015 and 209.25 ha in 2017. The most recent fluctuations were recorded in 2022 (142.29 ha) and 2023 (109.26 ha).

Settlement-related disturbances were first detected in 1993, impacting 94.41 ha, followed by 73.62 ha in 1994 and 30.15 ha in 1995. In 2017, disturbances due to settements resumed after a long period of no substantial activity, affecting 22.59 ha. Subsequently, there was an increase in activity in 2023, which affected 76.59 ha, and the peak was in 2019 at 135 ha.

Rubber plantation disturbances in Bago district from 1990 to 2023 exhibited various fluctuating patterns, and the peak disturbance occurred in 1991, with an area of 2,249.91 ha impacted, indicating a notable rubber plantation establishment. Subsequent disturbances were variable, with major peaks in 1995 (1,415.43 ha) and 2013 (1,448.64 ha), followed by another considerable rise in 2014 (2,222.10 ha). Although activity decreased in subsequent years, minor disturbances continued to occur, such as 401.49 ha in 2023.

Road-related disturbances in Bago district occurred in 2004, with 271.26 ha affected, followed by 114.84 ha in 2005. The most extensive development year for road infrastructure was 2008, when road construction impacted 507.6 hectares, resulting in a significant peak. The 33-year study period in Bago district was characterized by minimal mining-related disturbances, with only one recorded event. In 2021, mining activity was observed, impacting an area of 42.57 ha.

4.4 Disturbances in Pyay District between 1990 and 2023

Pyay district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 12). This data aggregates the yearly disturbances of shifting cultivation, plantation development and others. Each disturbance category indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

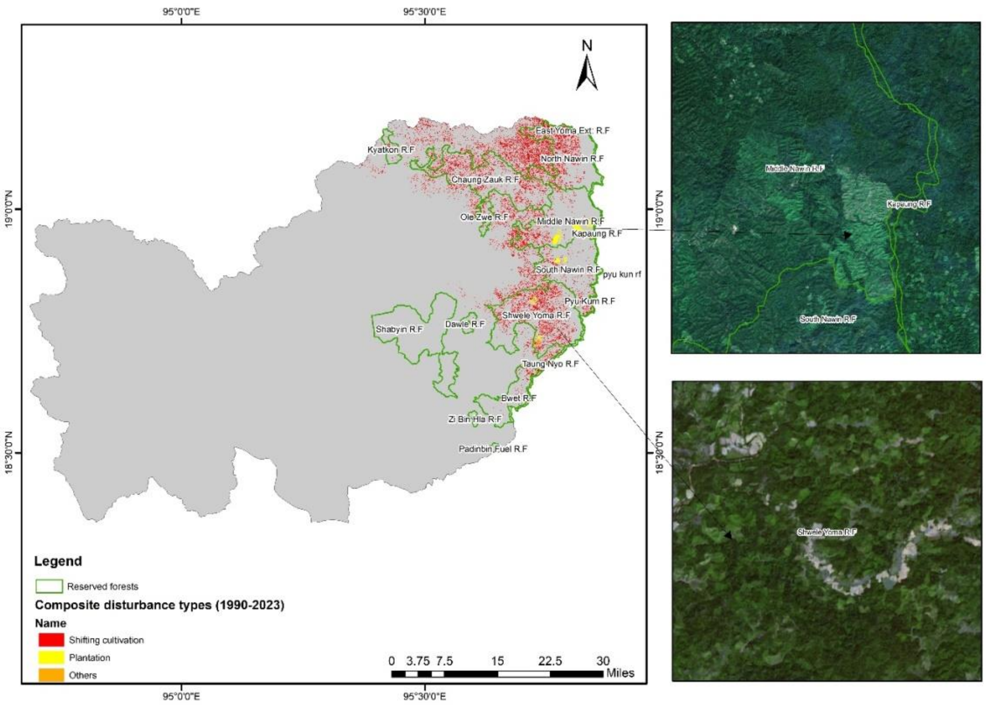

Figure 12: Spatial-temporal distribution of disturbance area in Pyay District

The total disturbed area across all categories is 23,732.46 ha, with 13,617.99 ha indicating signs of recovery (Figure 13). The most disturbed area, 22,076.55 ha, was caused by shifting agriculture, with 12,322.89 ha recovering to forests. Plantations impacted 1,558.26 ha, with 1,215.81 ha recovered. The "Others" category affected 97.65 ha, of which 79.29 ha indicated forest recovery.

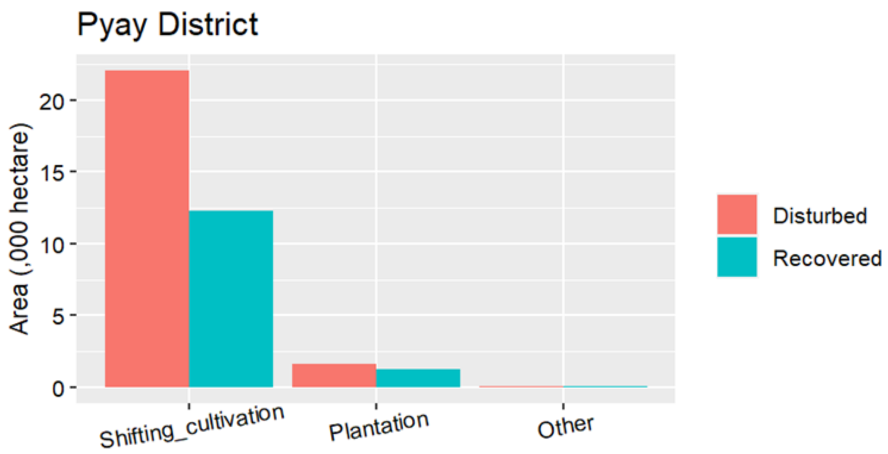

Figure 13: Total disturbed and recovered area of Pyay District

The practice of shifting cultivation in Pyay district from 1990 to 2023 was indicated significant temporal fluctuation with notable periods of intense activity. The earliest recorded disturbance was in 1992, affecting 1,087.83 ha. Subsequently, there was a significant increase in 1993 (2,797.38 ha) and 1994 (2,667.78 ha) (Figure 14). In 1995, there were no disturbances recorded, and activity decreased. However, it resumed in 1996 (965.07 ha) and reached 1,381.86 ha in 1997. After a period of reduced activity in 1998 and 1999, disturbances increased substantially in 2001, affecting 1,143.81 ha. The maximum single-year impact was achieved in

2002, with 3,505.32 ha of forest areas affected, signifying the peak of shifting cultivation during the study period. In subsequent years, the degree of disturbances increased with significant impacts recorded in 2004 (1,113.66 ha), 2007 (1,262.52 ha), and 2009 (1,499.4 ha). In recent years, shifting cultivation disturbances exhibited a decreasing trend except 860.94 ha in 2021, with smaller effects observed: 316.44 ha in 2019, 144.36 ha in 2021, and 276.3 ha in 2023.

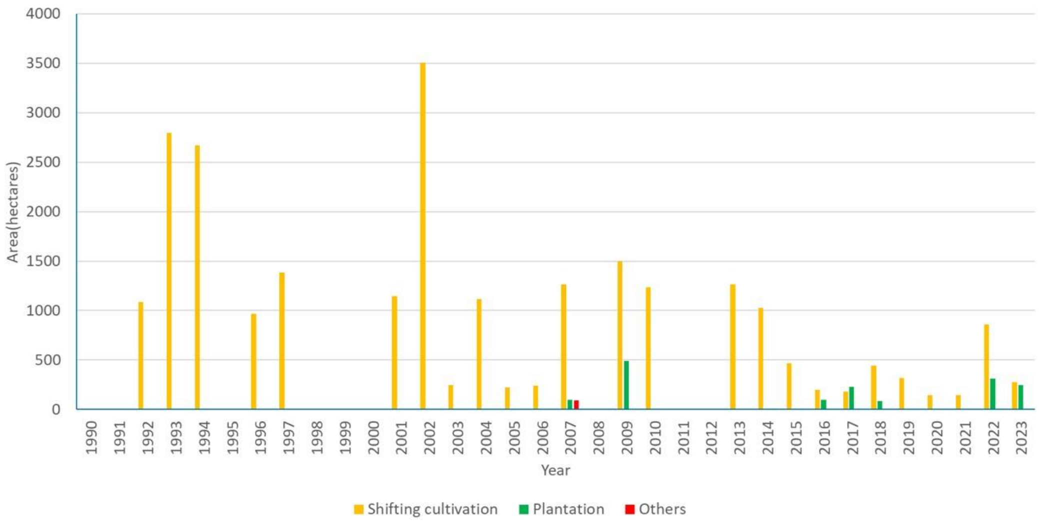

Figure 14: Temporal distribution of disturbed area in Pyay District

Between 1990 and 2023, plantation establishment in Pyay district occurred sporadically, characterized by significant periods of land conversion for plantation. In 2007, 96.75 ha of forest areas converted to plantation areas. This was followed by a significant expansion in 2009, where 488.43 ha were developed. Subsequent years exhibited sporadic activity, including 95.58 ha in 2016, 227.52 ha in 2017, and 87.57 ha in 2018. More recently, plantation development increased in 2022 (313.74 ha) and 2023 (248.67 ha).

Disturbances classified under the "Others" category in Pyay district between 1990 and 2023 were minimal. The first disturbance had occurred in 2007, impacting 92.16 hectares, being the most significant impact in this category. A minor disturbance of 5.49 hectares was detected in 2020, with no further activity recorded in subsequent years.

4.5 Disturbances in Tharawady District between 1990 and 2023

Tharawady district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 15). This data aggregates the yearly disturbances of shifting cultivation, dam construction, plantation establishment and others. Each disturbance category indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

The total disturbed area across all categories is 28,717.65 ha, with 12,543.39 ha indicating signs of recovery. The most disturbed area, 11,993.13 ha, was caused by shifting cultivation, with 7,336.44 ha recovering to forests (Figure 16). Conversely, construction of dams resulted in significant permanent disturbance, impacting 8,291.16 ha, with no recovery observed. Plantations impacted 6,999.03 ha**,** with 4,491.27 ha recovered. The "Others" category affected 1,434.33 ha, of which 715.68 ha indicated forest recovery.

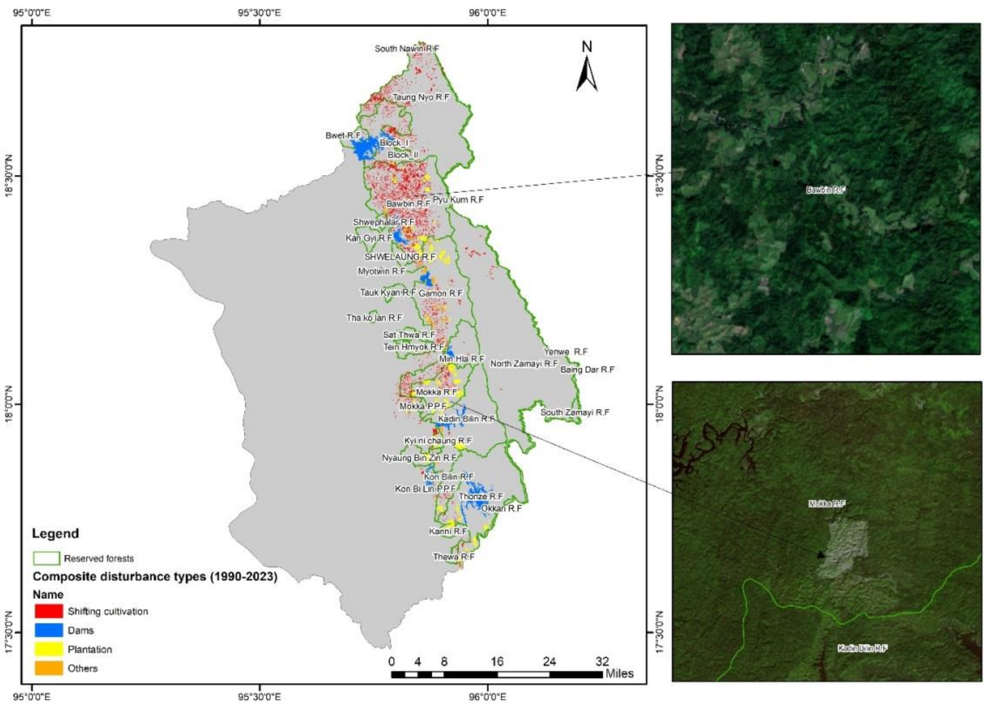

Figure 15: Spatial-temporal distribution of disturbance area in Tharawady District

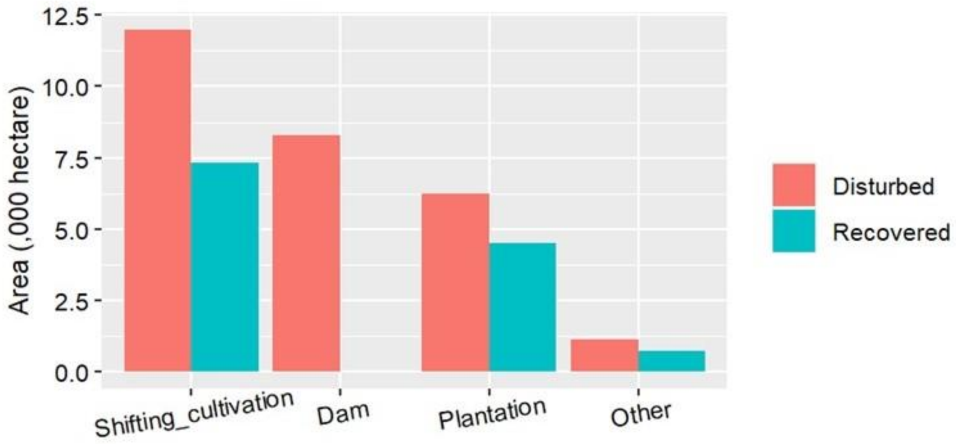

Figure 16: Total disturbed and recovered area of Tharawady District

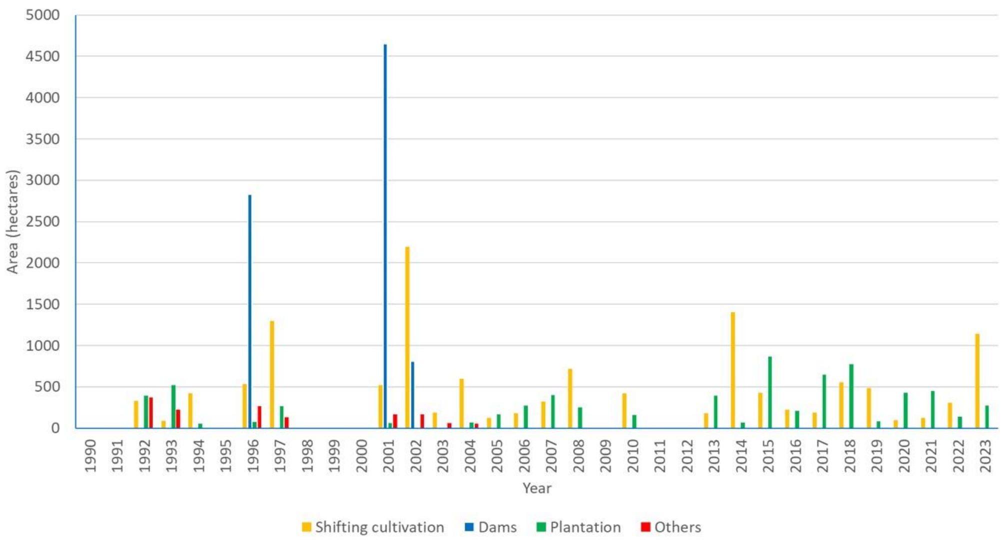

Figure 17: Temporal distribution of disturbed area in Tharawaddy District

Shifting cultivation in Tharawady district from 1990 to 2023 showed considerable temporal variability, characterized by varying degrees of disturbances on forest areas during the study period (Figure 17). The earliest recorded activity, which affected 326.43 ha, occurred in 1992. Subsequently, there was a decrease in 1993 (88.56 ha) and a significant increase in 1994 (418.14 ha). In 1996, shifting cultivation had an impact on 532.8 ha, and it further expanded in 1997 to 1,297.17 ha, resulting in one of the highest levels of disturbance during the study period. In the early 2000s, shifting cultivation increased, particularly in 2002, which recorded the biggest single-year disturbance at 2,191.05 ha. Other notable years were 2008 (715.05 ha) and 2014 (1,400.49 ha). In recent years, disturbances decreased but remained stable, with modest effects of 552.51 ha in 2018, 311.04 ha in 2022, and 1,138.59 ha in 2023.

Dam construction in Tharawady district from 1990 to 2023 occurred mostly in certain years, indicating significant land use change. The first significant event occurred in 1996, with the construction of the Taungnyo reservoir, affecting 2,829.15 hectares, indicating the beginning of extensive dam-related disturbances in the district. In 2001, there was a notable increase in dam construction, resulting in the establishment of many reservoirs and dams, such as the Bawbin reservoir, Kadin Bilin dam, The Daw dam, and Thonze dam, which combined disrupted 4,649.67 ha of forest areas. In 2002, construction activities were observed with the Min Hla dam and Ga Mon dam, impacting 812.34 ha. No further dam construction activities were recorded after 2002.

The initial forest land clearing for plantation establishment in Tharawady district was captured in 1992, including 390.87 ha, and subsequently expanded to 516.78 ha in 1993, representing the highest level of expansion during the early years. Plantation establishment decreased in subsequent years, including 1994 (50.22 ha) and 1996 (74.7 ha), and there was no significant activity during the latter part of the 1990s. During the early 2000s, plantation expansion was limited, represented by only 57.51 hectares in 2001. Nevertheless, there was a significant increase in activity during the mid-2000s, with notable expansions in 2005 (169.2 ha) and 2006 (270.72 ha). The period from 2015 to 2020 was characterized by the most extensive plantation establishment, as evidenced by the substantial conversions in 2015 (868.41 ha), 2018 (775.89 ha), and 2020 (426.6 ha). More recently, moderate expansions were observed in 2022 (141.48 ha) and 2023 (271.17 ha).

Disturbances categorized as "Others" in Tharawady district from 1990 to 2023 occurred occasionally, with increased activity in the early years of the study period. The first recorded disturbance occurred in 1992, impacting 371.43 ha, thereafter declining to 221.13 ha in 1993. Additional disturbances were observed in 1996 (268.29 ha) and 1997 (131.85 ha). During the early 2000s, the activity continued with 164.7 ha affected in 2001 and 163.8 ha in 2002, followed by lesser disturbances of 60.66 ha in 2003 and 52.47 ha in 2004.

4.6 Disturbances in Ottaya District between 1990 and 2023

Ottaya district includes Ottayathiri, Tatkon, Pokpathiri and Zayarthiri townships. Ottaya district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 18). This data aggregates the yearly disturbances of shifting cultivation, dam construction, road construction, plantation establishment, settlement development and others disturbances. Each disturbance category indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

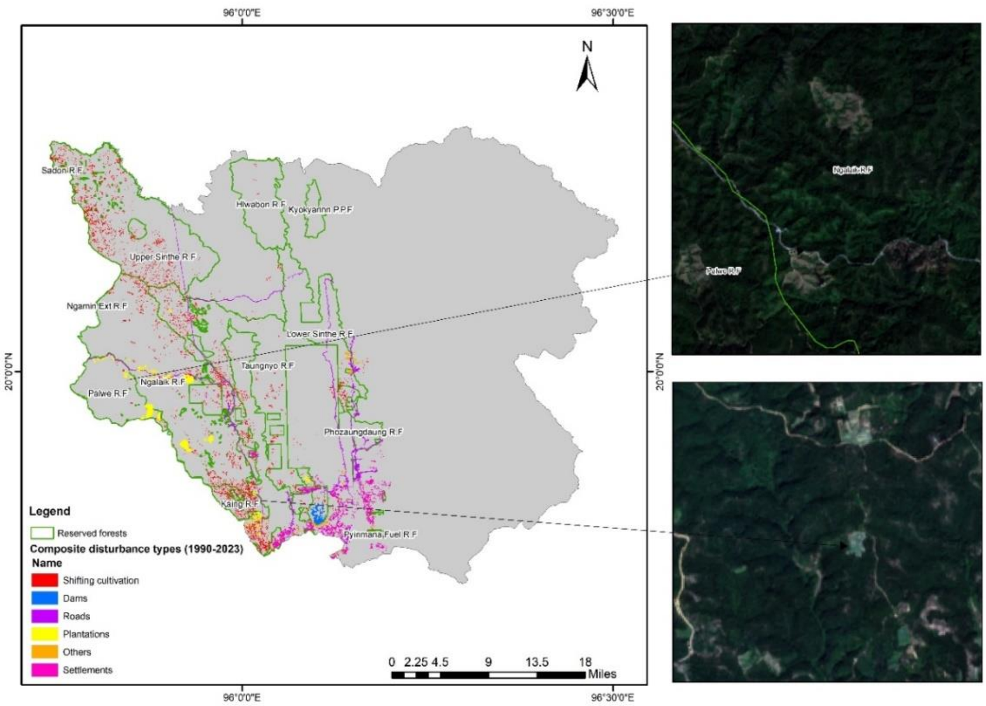

Figure 18: Spatial-temporal distribution of disturbance area in Ottaya District

The total disturbed area across all categories is 11,271.78 ha, with 3,273.03 ha indicating signs of recovery. Shifting cultivation included 4,654.98 ha, with 2,132.91 ha recovering to forest areas, indicating partial ecological recovery over time (Figure 19). Plantation establishment impacted 1,272.69 ha, with 874.35 ha stabilizing into long-term plantation areas. The "Others" category affected 459.09 ha, of which 265.77 ha indicated forest recovery. Dam construction resulted in a substantial and permanent loss of forest areas, impacting 294.57 ha with no possibility of recovery. The construction of roads impacted 2,484.63 ha, indicating permanent land use change due to infrastructure development. Settlements included an area of 2,082.96 ha, indicating a permanent transformation into residential zones, with no signs of recovery.

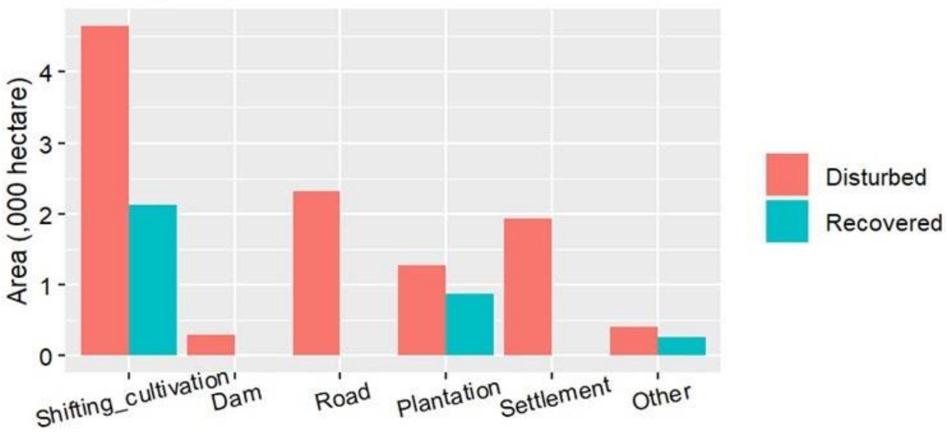

Figure 19: Total disturbed and recovered area of Ottaya District

Over the 33-year period from 1990 to 2023, shifting cultivation disturbances in Ottaya district indicated fluctuating patterns (Figure 20). The earliest shifting cultivation occurred in 1993, impacting 510.66 ha, thereafter declining to 343.08 ha in 1994. Disturbances decreased in 1996, impacting 118.26 ha, followed by a significant increase in 1998 (424.35 ha) and resulting in a peak in 2000 with 708.75 ha affected, indicating the highest level of disturbance recorded during the study period. During the 2000s, disturbances from shifting cultivation were minor, with notable years being 2001 (611.46 ha) and 2002 (469.35 ha), followed by lesser effects of 110.16 ha in 2003 and 137.88 ha in 2004. Activity continued at reduced levels in the following years, with disturbances varying from 123.48 ha in 2006 to 470.16 ha in 2010. From 2010 onwards, activity continued to decrease, with small disturbances recorded: 209.34 ha in 2015, 93.06 ha in 2021, and 56.97 ha in 2023.

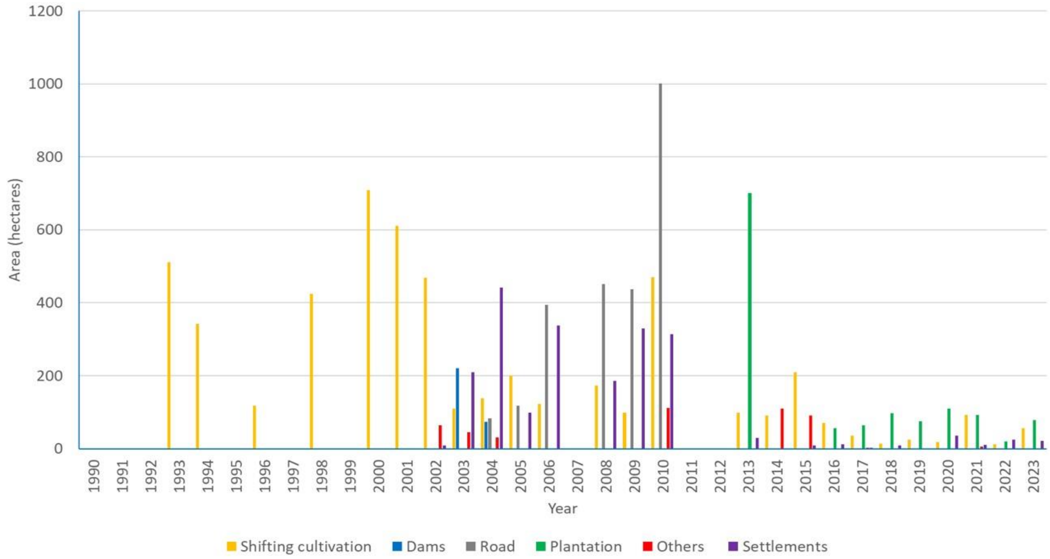

Figure 20: Temporal distribution of disturbed area in Oaktaya district

Dam construction in Ottaya district from 1990 to 2023 was only occurred for a short period in the early 2000s. In 2003, the Chaungmagyi dam was constructed, impacting 221.13 ha. This was followed by an extension of the same dam in 2004, affecting an additional 73.44 ha. No further dam construction activities were recorded in the district after 2004.

The road construction in Ottaya district throughout the study period from 1990 to 2023 exhibited a sporadic pattern, with notable activity occurring primarily between 2004 and 2010. The initial disturbance was detected in 2004, impacting 83.61 ha, and subsequently increased in 2005 to 117.72 ha. In 2006, road construction increased to 394.56 ha, continuing into 2008 with 451.17 ha and 2009 with 436.5 ha, indicating consistent progress over this timeframe. In terms of infrastructure development, the year 2010 had the greatest amount of road building, affecting 1,001.07 ha.

During the 1990–2023 research period, the majority of plantation establishment in Ottaya district took place in the latter years; the earliest activity was detected in 2013, affecting 700.56 ha. Following an initial peak in 2013, plantation establishment activity re-emerged in 2016 with 56.16 ha. This was followed by a steady increase in the following years, including 64.53 ha in 2017, 97.56 ha in 2018, and 75.6 ha in 2019. The peak plantation establishing during this subsequent year was observed in 2020, with 109.53 ha. Subsequently, activities decreased to 92.52 ha in 2021, 20.52 ha in 2022, and 78.57 ha in 2023.

The "Others" category in Ottaya district exhibited sporadic disturbances over the 33-year study period, with significant occurrences concentrated in a few specific years. The first recorded disturbance took place in 2002, impacting 63.81 ha, followed by 44.64 ha in 2003 and 30.42 ha in 2004, indicating a sequence of continuous activity. In 2010, the disturbance peaked, affecting the largest single-year area of 111.51 ha. In subsequent years, the extent of disturbances fluctuated, with significant impacts of 110.61 ha in 2014 and 90.81 ha in 2015, followed by slightly smaller occurrences of 2.07 ha in 2017 and 5.22 ha in 2021.

Settlement-related disturbances in the Ottaya district were first detected in 2002, including a limited area of 8.46 hectares. A notable increase occurred in 2003 and 2004, with 209.88 ha and 442.17 ha impacted, respectively. This was the most significant recorded settlement disturbance during the study period. In the following years, settlement-related disturbances continued, with 99.54 ha recorded in 2005 and an increase to 337.05 ha in 2006. In 2007, there was a temporary reduction in disturbance levels; however, these levels increased again in the following years, impacting 186.66 ha in 2008, 329.04 ha in 2009, and 314.37 ha in 2010. In recent years, settlement-related disturbances became less frequent and more dispersed, with smaller areas impacted, such as 29.79 ha in 2013, 35.1 ha in 2020, and 21.06 ha in 2023.

4.7 Disturbances in Dekkhina District between 1990 and 2023

Dekkhina district includes Lewe, Dekkhina, Zabuthiri, and Pyinmana townships. Dekkhina district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 21). This data aggregates the yearly disturbances of shifting cultivation, dam construction, road construction, plantation establishment, settlement development and others disturbances. Each disturbance category indicates the total area affected yearly, with certain areas experiencing repeated or overlapping disturbances as well as and others without any overlap.

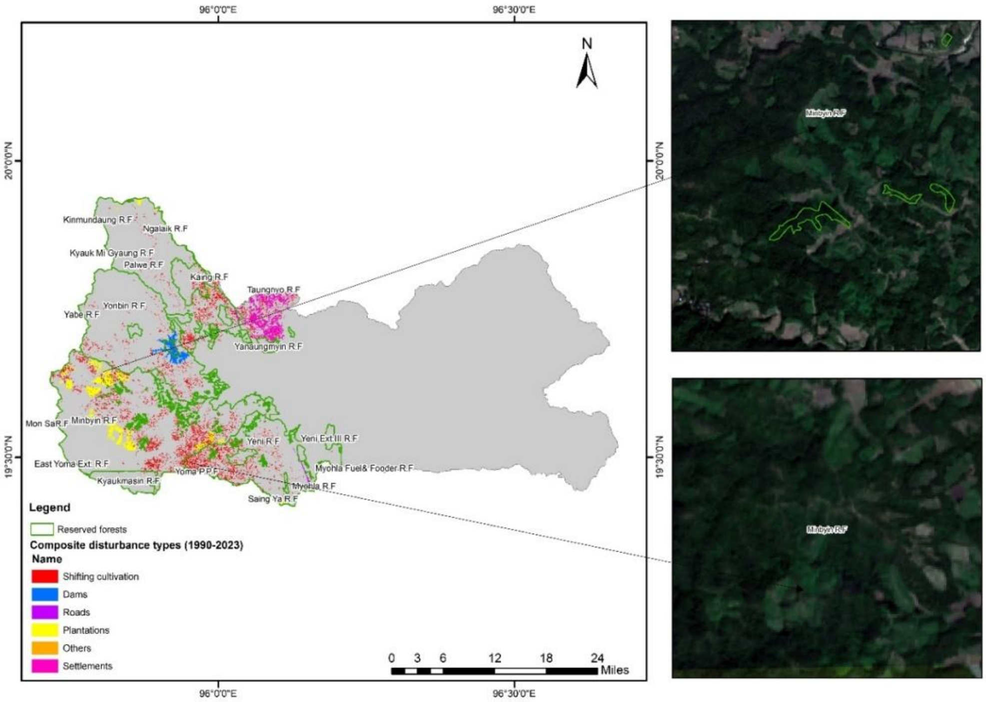

Figure 21: Spatial-temporal distribution of disturbance area in Dekkhina district

The total disturbed area across all categories is 18,125.82 ha, with 7,804.71 ha indicating signs of recovery. Shifting cultivation included 10,169.1 ha, with 5,282.28 ha recovering to forest areas, indicating partial ecological recovery over time (Figure 22). Plantation establishment impacted 3,460.5 ha, with 2,471.22 ha stabilizing into long-term plantation areas. The "Others" category affected 96.48 ha, of which 51.21 ha indicated forest recovery. Dam construction resulted in a substantial and permanent loss of forest areas, impacting 1,217.79 ha with no possibility of recovery. The construction of roads impacted 250.38 ha, indicating permanent land use change due to infrastructure development. Settlements included an area of 2,931.57 ha, indicating a permanent transformation into residential zones, with no signs of recovery.

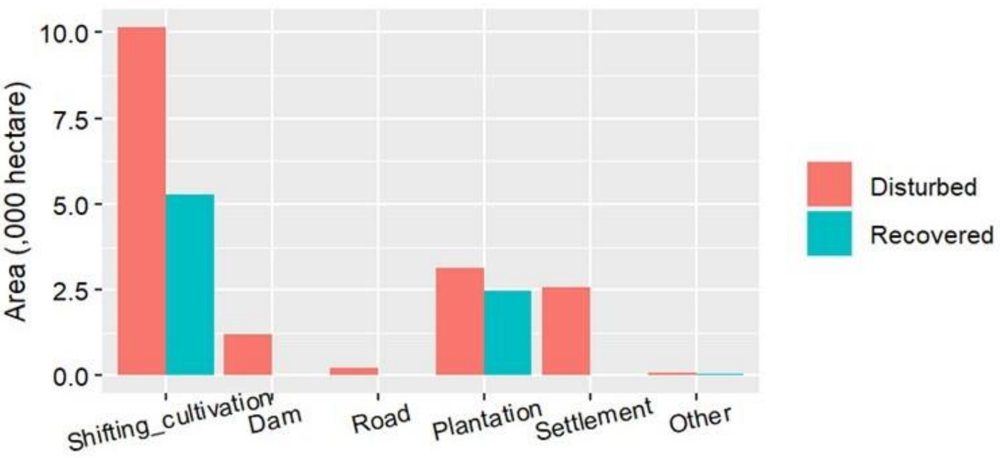

Figure 22: Total disturbed and recovered area of Dekkhina District

The practice of shifting cultivation in the Dekkhina district included significant variations throughout the 33-year study period from 1990 to 2023. The first recorded activity occurred in 1992, impacting 1,813.23 ha, marking one of the most significant yearly effects throughout the research period (Figure 23). Disturbance areas decreased in the following years, with 219.96 ha in 1993, 228.51 ha in 1994, and a further reduction to 187.47 ha in 1996. Activity increased again in 1997, to 485.46 ha, and continued with significant effects of 431.55 ha in 2000 and 574.65 ha in 2001. Between 2003 and 2008, there was a notable rise of shifting cultivation, characterized by substantial disturbances of 380.7 ha in 2003, 806.4 ha in 2004, and 922.05 ha in 2008, indicating one of the most intense phases for this activity. In 2009 and 2010, disturbances were significant, reaching 738.09 ha and 862.83 ha, respectively. A downward trend has been seen in recent years, with observed disturbances of 193.95 ha in 2017, 147.42 ha in 2022, and 198.45 ha in 2023.

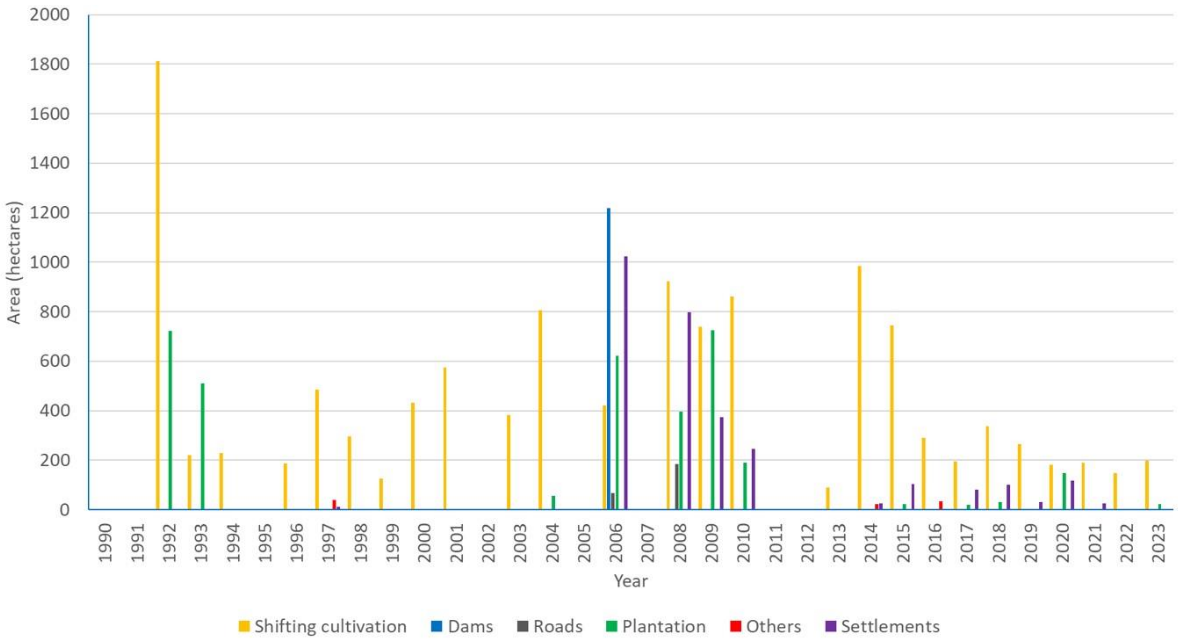

Figure 23: Temporal distribution of disturbed area in Dekkhina District

The dam construction activity in the Dekkhina district over the 33-year study period from 1990 to 2023 was marked by a notable occurrence in 2006, when the Chaungmange dam was built, affecting an area of 1,217.79 ha. During the 33-year research period (1990–2023), road construction in the Dekkhina district mostly occurred in 2006 and 2008, affecting 66.06 ha and 184.32 ha, respectively.

The plantation establishment in the Dekkhina district throughout the 33-year period from 1990 to 2023 was included in certain years. Initial activities in 1992 and 1993 accounted for 721.71 ha and 510.21 ha, respectively. Significant expansion resumed in 2006 and 2008, with 622.17 ha and 396.27 ha, respectively, followed by 724.95 ha in 2009 and 188.46 ha in 2010. Subsequent years showed smaller-scale expansions, including 148.14 ha in 2020 and 21.78 ha in both 2015 and 2023.

The "Others" disturbance category in the Dekkhina district exhibited sporadic activity throughout the 33-year period from 1990 to 2023. The disturbance was first detected in 1997, impacting 40.05 hectares. Subsequent disturbances were insignificant, with 23.13 ha in 2014 and 33.3 ha in 2016.

Settlement related disturbances in the Dekkhina district throughout the 33-year period from 1990 to 2023 were initially recorded in 1997, exhibiting an insignificant impact of 9.9 ha. In 2006, a substantial increase happened, impacting 1,023.3 hectares, followed by 798.12 hectares in 2008 and 373.32 hectares in 2009. Subsequent disturbances were moderate, including 244.35 ha in 2010, 104.13 ha in 2015, and 116.73 ha in 2020, along with lesser effects of 25.11 ha in 2021. These trends indicate the growth of urban areas and settlements across time.

4.8 Disturbances in Magway District between 1990 and 2023

Magway district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 24). This data aggregates the yearly disturbances of shifting cultivation, road construction and plantation establishment.

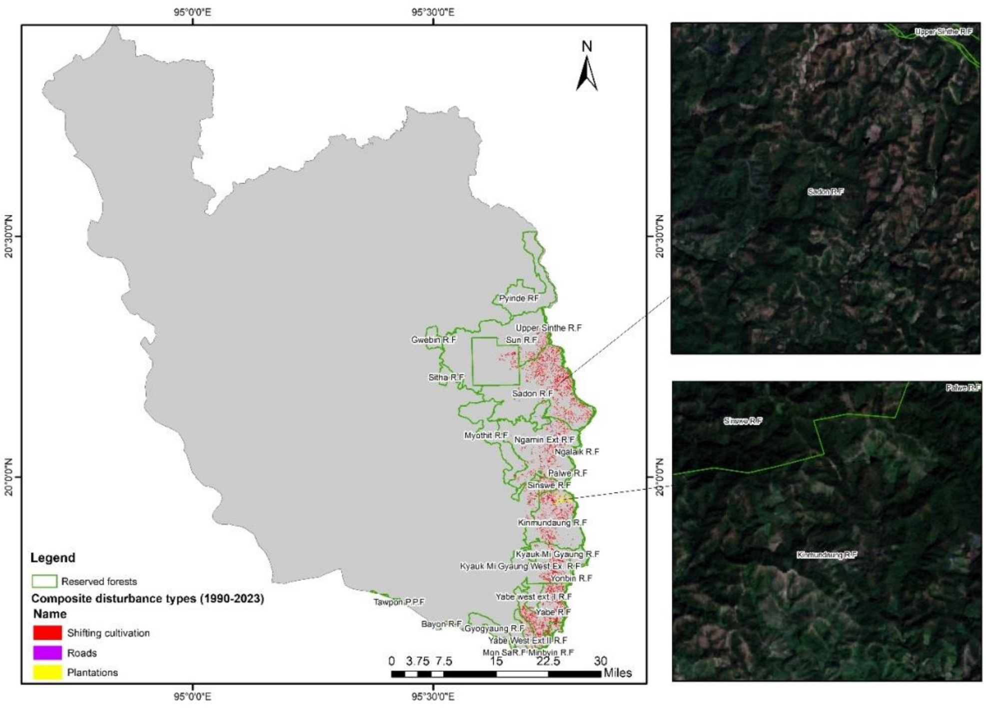

Figure 24: Spatial-temporal distribution of disturbance area in Magway district

The total disturbed area across all categories is 9,395.46 ha, with 3,944.88 ha indicating signs of recovery. The most disturbed area, 9,026.91 ha, was caused by shifting cultivation, with 3,843 ha recovering to forests. Plantations impacted 228.69 ha**,** with 101.88 ha recovered (Figure 25). Conversely, road development resulted in 139.86 ha of disturbed land with no recovery, indicating its permanent impact.

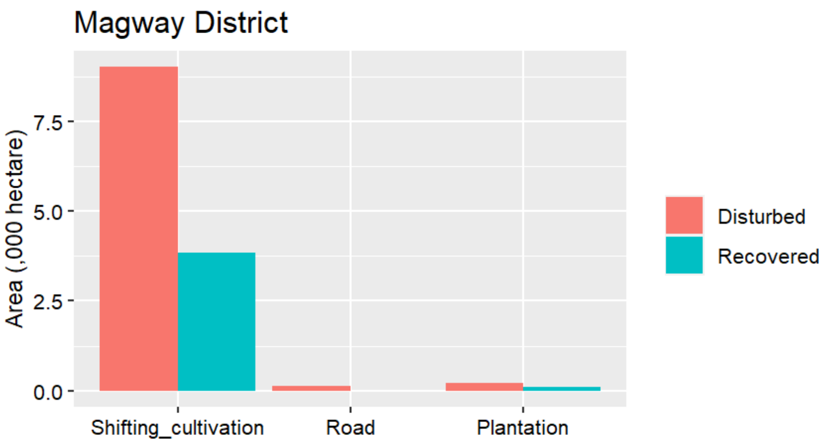

Figure 25: Total disturbed and recovered area of Magway District

Over the 33-year period from 1990 to 2023, shifting cultivation disturbances in Magway district indicated fluctuating patterns (Figure 26). No disturbances were detected in the early years (1990–1992). The first significant activity was observed in 1993, impacting 525.96 ha, followed by a larger disturbance in 1998, affecting 754.29 ha. In 2000, shifting cultivation expanded further, affecting 845.73 ha. This was followed by 874.44 ha in 2002 and a peak of 1,060.56 ha in 2004. During the period (2005–2013), disturbance levels were comparatively moderate, with the highest recorded fluctuations, including 483.21 ha in 2005, 596.97 ha in 2008, and 1,323.99 ha in 2010, occurring during the study period. There was a substantial decrease in shifting cultivation activity after 2013, with smaller impacts, such as 74.61 ha in 2018 and 107.46 ha in 2023.

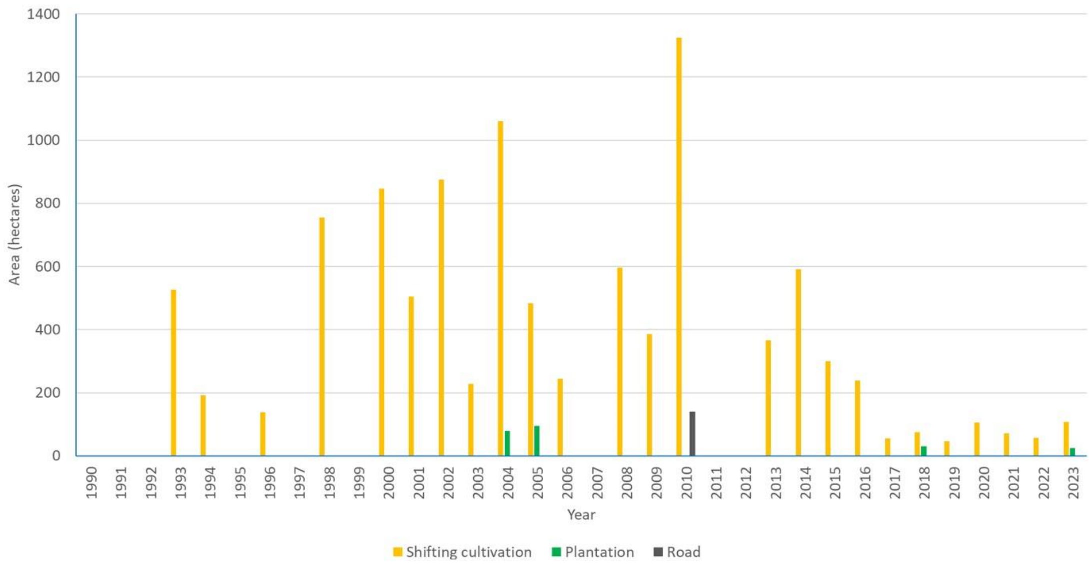

Figure 26: Temporal distribution of disturbed area in Magway District

No plantation establishment was detected between 1990 and 2003. The first recorded activity occurred in 2004, with 79.02 ha established, followed by a modest growth in 2005 to 95.22 ha. After this period, plantation development remained absent in most years, except smaller expansions of 30.15 ha in 2018 and 24.3 ha in 2023. During the research period, road construction in Magway District was minimal, with activity recorded just in 2010, impacting an area of 139.86 ha.

4.9 Disturbances in Thayet District between 1990 and 2023

Thayet district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 27). This data aggregates the yearly disturbances of shifting cultivation and road construction and plantation development.

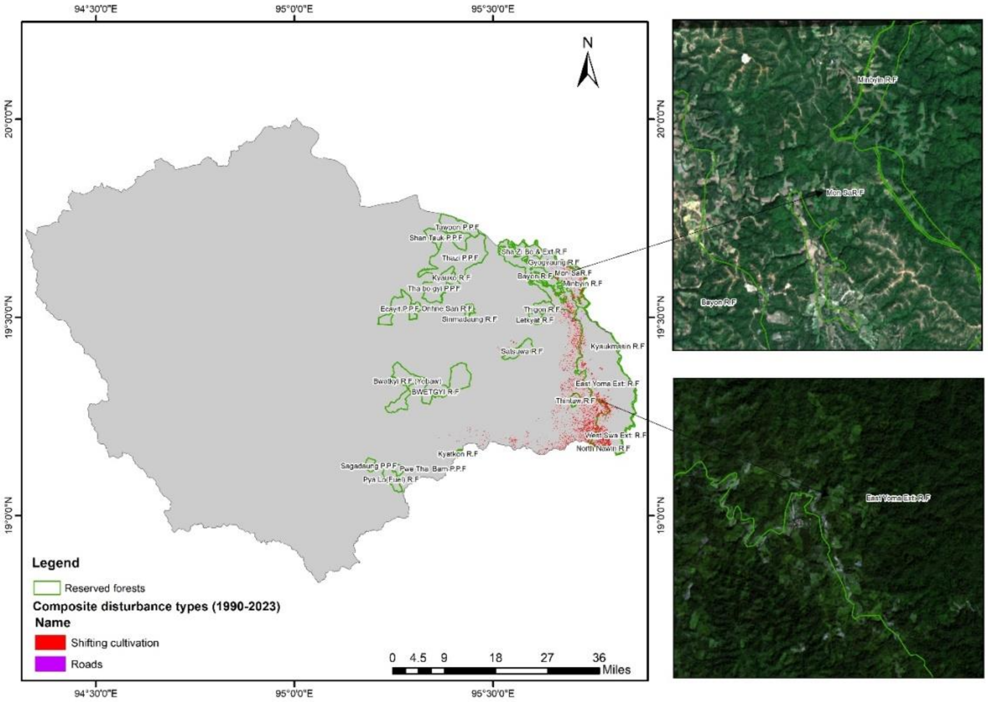

Figure 27: Spatial-temporal distribution of disturbance area in Thayet District

The total disturbed area across all categories is 7,596.81 ha, with 4130.91 ha indicating signs of recovery. The most disturbed area, 7,431.75 ha, was caused by shifting agriculture, with 4,130.91 ha recovering to forests. Conversely, road development resulted in 165.06 ha of disturbed land with no recovery, indicating its permanent impact (Figure 28).

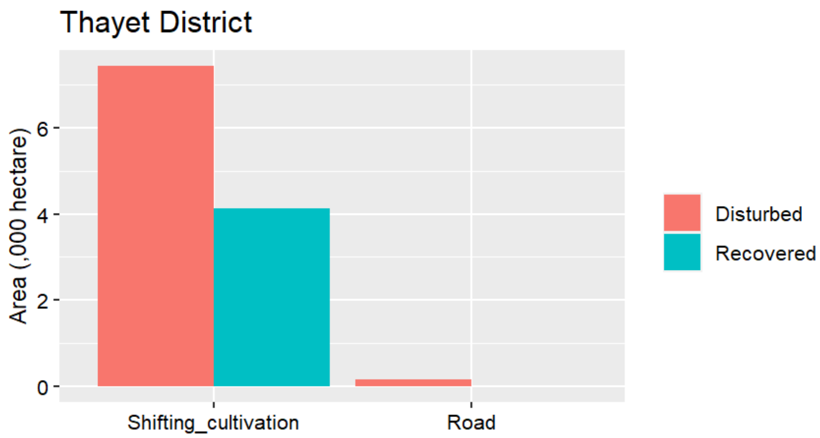

Figure 28: Total disturbed and recovered area of Thayet District

Over the 33-year period from 1990 to 2023, shifting cultivation disturbances in Thayet district indicated fluctuating patterns. No disturbances occurred in 1990 and 1991; nevertheless, activity began in 1992, impacting 403.2 ha (Figure 29). Moderate levels were detected in 1994 (119.07 ha) and 1996 (404.55 ha), followed by a significant peak in 1999, affecting 637.38 ha. During the early 2000s, disturbances continued at a relatively consistent level, with 406.35 ha in 2000 and 467.73 ha in 2003. The mid-period (2004–2013) was characterized by varying levels of shifting cultivation, with activity reaching 427.23 ha in 2004 and 400.68 ha in 2008. In the subsequent years, there were significant fluctuations, particularly in 2017 (514.53 ha) and 2018, which exhibited the highest disturbance recorded during the study period at 883.71 ha. The Thayet district experienced minimal road construction disturbances over the 33-year period (1990–2023), with activity only being recorded in 2010 and affecting a total area of 165.06 ha.

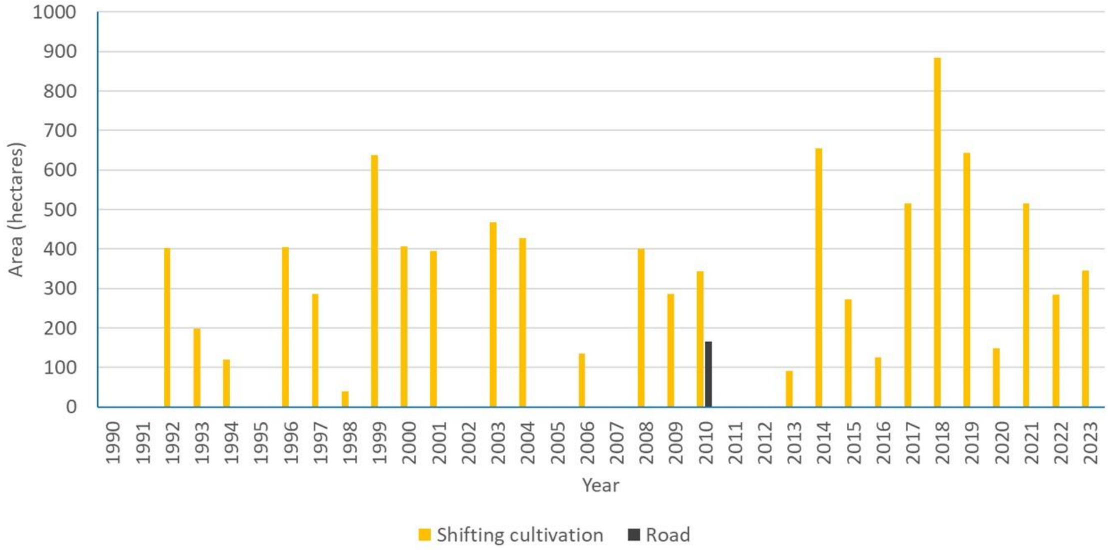

Figure 29: Temporal distribution of disturbed area in Thayet District

4.10 Disturbances in Yangon (North) District between 1990 and 2023

Yangon (North) district's composite disturbance data shows the aggregated disturbed areas for each disturbance type over a 33-year period (1990–2023) (Figure 30). This data aggregates the yearly disturbances of shifting cultivation, dam construction, plantation establishment, settlement, rubber and others.

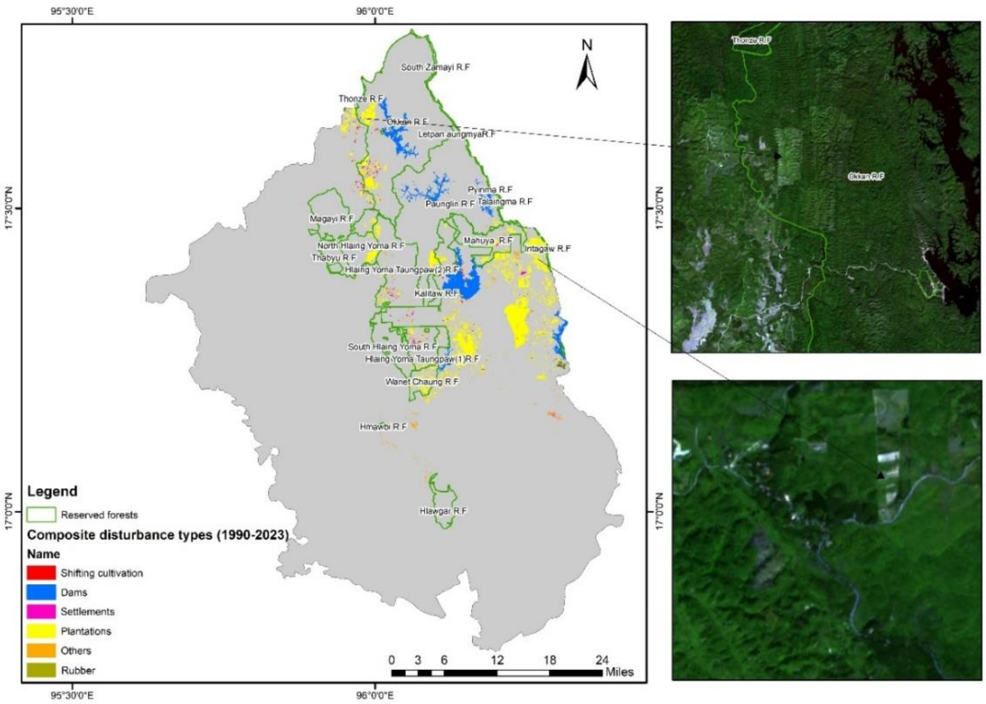

Figure 30: Spatial-temporal distribution of disturbance area in Yangon North District

The total disturbed area across all categories is 22,914.18 ha, with 11,593.35 ha indicating signs of recovery. Plantation establishment resulted in land conversion covering 14,496.57 ha, with 10,237.68 ha transitioning into stable plantation areas (Figure 31). Shifting cultivation impacted 524.79 ha, with 373.95 ha recovering to forested areas. The "Others" category affected 1,284.75 ha, of which 892.71 ha indicated forest recovery. Dam construction resulted in a substantial and permanent loss of forest areas, impacting 6,345.27 ha with no possibility of recovery. Additionally, settlements disturbed 113.04 ha indicating no recovery as these areas remain urbanized. Rubber plantations impacted 149.76 ha, with 89.01 ha stabilizing as sustained rubber plantation lands, indicating their continuing use for agricultural output instead of returning to forests.

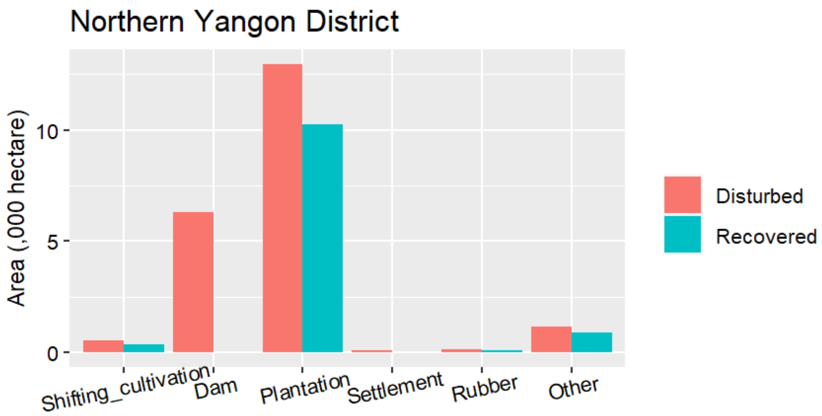

Figure 31: Total disturbed and recovered area of Yangon North District

Disturbances from shifting cultivation in Yangon (North) District from 1990 to 2023 were minimal, with small-scale activity observed in years. Disturbances were minor until 1997, when a significant area of 14.49 hectares was impacted (Figure 32). The most substantial activity occurred in 2001, affecting 90.72 ha, followed by 51.57 ha in 2003 and 42.03 ha in 2004. From 2005 onward, disturbances fluctuated, with significant years being 2010 (57.06 ha), 2013 (38.97 ha), and 2015 (48.24 ha). In recent years, there has been a minor rise in activity, with 62.91 ha impacted in 2022 and 66.24 ha in 2023.

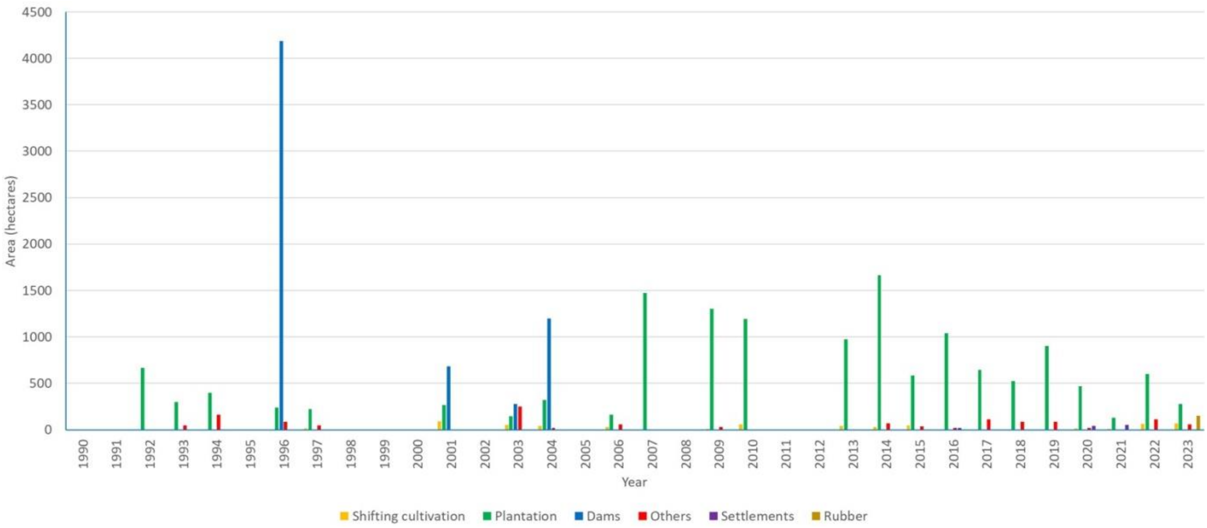

Figure 32: Temporal distribution of disturbed area in Yangon (North) District

The first plantation establishment occurred via LandTrendr algorithm in 1992, with 667.62 ha developed, followed by minor extensions in 1993 (301.59 ha) and 1994 (399.42 ha). The late 1990s and early 2000s were characterized by sporadic activity, with notable developments occurring in 1996 (237.96 ha), 1997 (222.93 ha), and 2001 (267.48 ha). The most notable increase occurred in 2007, with the establishment of 1,472.76 ha of plantations, followed by 1,301.85 ha in 2009 and 1,194.57 ha in 2010. In the subsequent years, plantation expansion progressed with significant increases, including 974.88 ha in 2013, 1,661.85 ha in 2014 (the most substantial single-year expansion), and 1,039.77 ha in 2016. In recent years, plantation development progressed steadily, with 600.39 ha established in 2022 and 276.66 ha in 2023.

Between 1990 and 2023, dam construction activities had a considerable impact on the forest areas in Yangon (North) district. The most significant disturbance occurred in 1996, affecting 4,185.63 ha due to the construction of the Nga Moe Yeik Dam and Tabula Dam, representing the most extensive dam-related activity throughout the study period. The La Gun Pyin Dam was constructed in 2001, which resulted in the disturbance of an additional 685.62 ha of forest areas. In 2003, the Ka Li Htaw Dam was constructed, impacting 275.58 hectares, followed by the Paung Lin Dam and Mahuyar Dam in 2004, which together affected 1,198.44 ha of forest areas. No further dam construction activity was detected by Landtrendr algorithm after 2004.

Disturbances categorized as "Others" in Yangon (North) district between 1990 and 2023 were sporadic. The first recorded activity was in 1993, affecting 48.87 ha, followed by a significant increase in 1994 with 162.18 ha disturbed. Minor disturbances were recorded in 1996 (83.61 ha) and 1997 (45.72 ha), however the most significant disturbance in the early period occurred in 2003, affecting 247.68 ha. Subsequent years showed minor and sporadic activity, notable disturbances in 2009 (27.72 ha), 2014 (66.69 ha), 2017 (112.77 ha) and 2019 (84.78 ha). In subsequent years, 112.14 ha were affected in 2022 and 59.04 ha in 2023.

Settlement-related disturbances in the Yangon (North) district from 1990 to 2023 were minor and occurred only in the latter years of the study period. No disturbances were found until 2016, at which time 16.92 ha were impacted. The largest settlement-related disturbance recorded during the study period was 40.77 ha in 2020, followed by 51.03 ha in 2021. In 2023, a disturbance of 4.32 ha was observed on a minor scale. The only occurrence of rubber plantation development during the study period was the 149.76 ha that were affected in 2023.

5. Discussion

5.1 Implications for forest disturbances in Bago Yoma

In this study, LandTrendr algorithm was applied to detect forest disturbance using Landsat satellite images, and the long-span monitoring and analysis of forest disturbance in Bago Yoma including nine districts were conducted from 1990 to 2023. The findings of this study can facilitate forest dynamics data base for the Forest Department of Myanmar with low cost via remote sensing technology.

The major causes forest disturbance all over the world could be divided into human and natural factors, of which human factors played a dominant role in this study(Wang et al., 2022). Since the previous decades, the government and local people began to realize the serious consequences of deforestation, and conducted reforestation activities and forest management in Bago Yoma. From the perspective of dominant tree species, the forest area of Bago Yoma was dominated by Teak and valuable hardwood species, and gradually changed to bamboo mixed degraded forests (Kyaw et al., 2020). Additionally, as Bago Yoma is the mixed deciduous forest type, natural disasters like forest fire occur frequently. During the study period, the Bago Yoma's forest disturbance was heavy, mainly resulting from shifting cultivation, construction of dam and road, and other economic activities. The substantial interquartile range (IQR) value 1.92 indicates that the middle 50% of yearly disturbed areas resulting from shifting cultivation covers a significant range, from 3,340 to 5,260 ha. This large range implies considerable fluctuations in the level of forest disturbance from year to year, which can be attributed to inconsistent shifting cultivation practices. Under this traditional farming approach, a particular area of land is cleared for agriculture, cultivating it for a few years, and then moving to a new area, allowing the previously used land to recover. The timing, location, and intensity of these activities can vary widely depending on several conditions like people's economic situations, soil fertility, variations in precipitation.

Shifting cultivation, the most dominant disturbance type in Taungnoo district, impacted over 42,165 ha. In Pyay district, shifting cultivation has significantly impacted 22,076.55 ha of forest land. Tharawady district also showed persistent disturbances of shifting cultivation impacted 11,993.13 ha highlighting the need for interventions to reduce shifting cultivation practice. To protect Bago Yoma forests scientifically and effectively, relevant government departments should take appropriate measures to protect forest resources in areas with high forest disturbance (e.g., Taungnoo, Pyay and Tharawaddy districts), improve the level of forest supervision and slow down the reduction of forest area caused by the expansion of shifting cultivation, human encroachment. Additionally, people should raise awareness of forest protection, reduce illegal logging and raising silvicultural operations like enrichment planting.

Rubber plantations in Bago district impacted 15,761.34 ha, with many areas stabilizing as agricultural systems. However, their water demand and replacement of natural forests raise concerns for both watershed health and biodiversity. Watershed conservation plays a critical role in maintaining both hydrological and ecological stability in the Bago Yoma region. Restoration in watershed zones, particularly upstream of dams and reservoirs, should prioritize native species to stabilize soils. Reducing human encroachment and strengthening economic and sustainable agricultural activities are suggested to mitigate the possibility of forest disturbance change to a certain extent in this area.

5.2 Advantages of the LandTrendr Algorithm for Forest Disturbance Studies

The LandTrendr algorithm is a highly effective method for identifying the spatial and temporal distribution of forest disturbance, as well as determining the year of disturbance and the land area affected. This study employed the LandTrendr method to investigate forest disturbances and recovery in Bago Yoma, utilizing two indices: NDVI and NBR, for disturbance detection and forest recovery. It offers important information for forest management because of its ability to identify both sudden changes, like dam construction, and gradual processes, like forest regeneration. Although false alarms were generated in certain areas, the false alarms caused by external factors (e.g., image stitching, thick and dense clouds) were significantly reduced in comparison to a single index, thus making the forest disturbance detection results more reliable(Wang et al., 2022).

5.3 Uncertainty in Forest Disturbance

This study has been conducted over thirty-three years. For long time series studies, Landsat TM/ETM/OLI series data is the more commonly used data source with a resolution of 30 m(Viana et al., 2019; Wulder et al., 2012; Yan et al., 2019; Zhu et al., 2021). However, there are some issues with using the Landsat series satellites during the study. For example, there were data gaps for the year 2011 and 2012 which in turn might affect the change detection results. Cloud cover in long time series change detection can also affect forest disturbance results. When Landsat data are missed in some years with persistent cloud cover, it may lead to undetected forest disturbances, particularly for rapid landuse changes like plantation establishment. Seasonal constraints also play a crucial role. If forests are cleared outside the satellite image range (November–January), disturbances may be missed or misclassified, especially if rapid vegetation regrowth occurs within the analysis period. Lastly, spectral confusion also affects the forest disturbance detection. Early-stage plantations and natural regrowth can have similar spectral signatures, causing LandTrendr to misclassify plantations as non-disturbance areas, leading to underestimation of plantation areas. Therefore, the LandTrendr algorithm produces many small ranges of false detections and less satisfactory results for some years which may also affect the forest disturbance results(Yan et al., 2019).

6. Conclusion

This study explored the spatial and temporal distribution of forest change in Bago Yoma from 1990-2023 using the LandTrendr algorithm and analyzed the forest disturbance types and amount in the area. The results showed the following:

(1) During the study interval in Bago Yoma, Bago Yoma experienced a total forest area loss of 132,921.02 ha. The area of forest disturbance was small in Thayet, Magway and moderate in Yangon(North), Dekkhina and Ottaya districts, and relatively large in Taungnoo, Bago, Pyay and Tharawady districts.

(2) Forest area changes in Bago Yoma were caused by converting forest areas into non-forest land for construction projects, such as building dams and roads, as well as shifting cultivation. Moreover, over-detection of image stitching and thick, dense clouds can affect the forest change results.

In conclusion, this study provides essential baseline data on the spatial and temporal forest disturbance types and amount in Bago Yoma, and will support forest managers to develop effective strategies in addressing district-specific challenges.

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