NEPAL

Proposed Forest Reference Level (FRL) (2008-2017)

Government of Nepal
Ministry of Forests and Environment
REDD Implementation Center
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ABBREVIATIONS

AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AMSL	Above Mean Sea Level
ART	Architecture of REDD+ Transactions
AGB	Above-ground biomass
BGB	Below-ground biomass
BTR	Biennial Report
BTR	Biennial Technical Report
CBFM	Community Based Forest Management
CDM	Clean Development Mechanism
CF	Community Forest
CEO	Collect Earth Online
CFUGs	Community Forest User Groups
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Conference of the Parties
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
DFRS	Department of Forest Research and Survey
DOM	Dead Organic Matter
DUR	Duration of Change
ETM	Enhanced Thematic Map
EF	Emission Factors
EIA	Environmental Impact Assessment
ER	Emission Reductions
ER-MR	Emissions Reductions Monitoring Report
EPRD	Emission Reduction Programme Document
ERPA	Emission Reduction Purchase Agreement
ERP	Emission Reduction Programme
FAO	Food and Agriculture Organization
FCIP	Free, Prior, and Informed Consent
FCPF	Forest Carbon Partnership Facility
FRA	Forest Resources Assessment
FREL	Forest Reference Emission Level
FRL	Forest Reference Level
FRTC	Forest Research and Training Centre
GCF	Green Climate Fund
GEE	Google Earth Engine
GFOI	Global Forest Observations Initiative
GHGI	Greenhouse Gas Inventory
GLAD	Global Land Analysis and Discovery Lab
GRM	Grievance Redress Mechanism

Ha	Hectare
HHs	Households
ICIMOD	International Centre for Integrated Mountain Development
IEE	Initial Environmental Examination
IPCC	Intergovernmental Panel on Climate Change
LandTrendr	Landsat-based Detection of Trends in Disturbance and Recovery
LEAF	Lowering Emissions by Accelerating Forest Finance
LRMP	Land Resource Mapping Project
LULUCF	Land Use, Land-Use Change and Forestry
M	Meters
MAG	Magnitude of Change
MGD	Methods and Guidance from the Global Forest Observations Initiative
MODIS	Moderate Resolution Imaging Spectroradiometer
$MtCO_2e$	Metric Ton Carbon Dioxide Equivalent
MRV	Monitoring, Reporting, and Verification
NC	National Communications
NBR	Normalized Burn Ration
NDCs	Nationally Determined Contributions
NDVI	Normalized Difference Vegetation Index
NFMS	National Forest Monitoring System
N_2O	Nitrous Oxide
NC3	Third National Communication 2021
NFI	National Forest Inventory
NLCMS	National Land Cover Monitoring System
NOAA	National Oceanic and Atmospheric Administration
NRSC	National Remote Sensing Center
OSM	Open Street Map
OWL	Other Wooded Land
RBP	Result Based Payment
R-PIN	Readiness Plan Idea Note
R-PP	Readiness Preparation Proposal
PREVAL	Pre-disturbance spectral value
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SIG	Spatial Informatics Group
SOC	Soil Organic Carbon
T	Ton
TACCC	Transparency, Accuracy, Consistency, Comparability, Completeness
tCO2e	Tonnes Carbon Dioxide Equivalent
tDM	Tonnes Dry Matter
TAR	Technical Assessment Report
TM	Thematic Map
TNC	Third National Communication
TMR	and TREES Monitoring Report
TREES	The REDD+ Environmental Excellence Standard
TRD	TREES Registration Document

UMD	University of Maryland
UN	The United Nations
UNFCCC	United Nations Framework Convention on Climate Change
REDD	Reducing Emissions from Deforestation and Forest Degradation
VVB	Validation and Verification Body
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping
YOD	Year of Distribution

EXECUTIVE SUMMARY

Nepal's Forest Reference Level (FRL), one of the four main elements of REDD+ according to the UNFCCC, enables the measurement of performance of results-based REDD+ activities associated with the implementation of national REDD+ strategy for Nepal. After stakeholder consultations and technical discussions, it has been determined that Nepal's FRL will be at national level, reflecting the historical period 2008-2017, and includes the activities reduction of emission from deforestation, reduction of emission from forest degradation and enhancement of forest carbon stock (afforestation/reforestation). Based on the availability, consistency, and reliability of historical and national-level data, the FRL will include only CO_2 and the carbon pools of above-ground biomass and below-ground biomass.

FREL construction followed the guidance and guidelines of IPCC and the UNFCCC Decisions 12/CP.17 and 13/CP.19. Forest Resource Assessment (FRA) data of 2016-2021 served as the fundamental sources of biomass estimates across different physiographic regions of the country, which were further used to derive emissions and removals. Remote sensing data from Landsat TM/ETM/Landsat 8 for the period 2008-2017, along with land cover maps from 2008 and 2017, were used to prepare the forest cover change map for the reference period. Change map strata (stable forest, deforestation, forest degradation, forest enhancement, and stable non-forest) were developed using the LandTrendr algorithm. The area estimate of activity data was obtained through unbiased area estimation, using visual interpretation of samples. Visually interpreted sample data (reference data) collected in higher-resolution images from Collect Earth Online and Google Earth were used to develop activity data on deforestation, forest degradation, and afforestation. A total of 22,385 ha and 485,612 ha are estimated to have undergone deforestation and forest degradation, respectively, during 2008-2017. Similarly, a total of 302,833 ha of land are converted into forest from other land uses between 2008 and 2017, contributing to the enhancement of forest carbon stock.

Forest degradation due to other drivers such as illegal timber harvesting, grazing, infrastructure development and forest fires, and enhancement of forest cover due to community forestry and other government initiatives and programs, are all believed to be of significance.

The uncertainty of emission and removal estimates was analyzed using a Monte Carlo simulation. The annual emissions due to deforestation and forest degradation are estimated at 958,601 t CO_2e/year and 8,572,211 t CO_2e/year, respectively. It is estimated that the annual enhancement of forest carbon stock due to reforestation and afforestation in other land uses resulted in removals of 2,535,863 t CO_2e/year. **The FRL, as per the three currently considered activities, therefore contains emissions of 958,601 t CO_2e/year for deforestation, emissions of 8,572,211 t CO_2e/year for forest degradation and removals of 2,535,863 t CO_2e/year for enhancement of forest carbon stocks.**

1. INTRODUCTION

1.1. Background

This submission presents Nepal's Forest Reference Level (FRL), covering both emissions and removals, in accordance with UNFCCC decisions 12/CP.17 and 13/CP.19. It builds upon Nepal's previously submitted FRL and incorporates methodological refinements and improved data sources, enabling the inclusion of additional carbon pools, expanded coverage of Reducing Emissions from Deforestation and Forest Degradation - REDD+ activities, and the application of direct measurement approaches for estimating emissions and removals.

Nepal, on a voluntary basis, proposed the first FRL[1] based on historical average emissions over the 2000 to 2010 period, covering the activities of reducing emissions from deforestation and forest degradation (partly) and enhancement of forest carbon stocks (removals). The first FRL of national scale was submitted to the UNFCCC Secretariat in January 2017 and was reviewed by technical experts in 2018, facilitated by the UNFCCC Secretariat[2].

Decision 12/CP.17 paragraph 12, agrees that a developing country Party should periodically update the forest reference emission level and/or FRL as appropriate, considering new knowledge, new trends and any modification of scope and methodologies.

Nepal has adopted a stepwise approach to FRL development, following paragraph 10 of Decision 12/CP.17. Consequently, FRL has been improved by incorporating better data, enhanced methodologies, and additional pools, highlighting the importance of adequate and predictable support as mentioned in paragraph 71 of Decision 1/CP.16.

Nepal underlines that the submission of the FRL is voluntary and exclusively to obtain and receive payments for REDD+ activities, under paragraph 2 of Decisions 13/CP.19, and paragraphs 7 and 8 of Decision 14/CP.19. The updated FRL will serve as a national reference for the forestry sector in reporting GHG emissions nationally and internationally. In terms of subsequent use of the FRL in whole or in part of it in the pursuance of REDD+ payment undertaken by Nepal with other Parties or organizations, Nepal will ensure, as far as possible, to maintain the principles of Transparency, Accuracy, Consistency, Comparability, Completeness (TACCC) and to avoid double-counting and double-payment.

Consequently, the submission does not amend, revise, or adjust Nepal's commitments or position in the National Communications (NC), Biennial Technical Report (BTR) and the Nationally Determined Contributions (NDCs) submitted by Nepal in the context of the Paris Agreement. Instead, it maintains consistency with these submissions. This FRL has

[1] https://redd.unfccc.int/files/finalfrlnepal_jan2018.pdf
[2] http://unfccc.int/resource/docs/2017/tar/npl.pdf

undergone several improvements following the recommendation from the technical assessment of the 1st FRL.

1.2. Objectives

The main objective of this updated national FRL is to strengthen the technical robustness and transparency of its REDD+ framework by incorporating recommendations from the UNFCCC's technical assessment of the FRL submitted in 2017. The proposed FRL also reflects improvements and updates in data sources and methodologies and establishes an approved benchmark to enable access to REDD+ results-based payments, particularly through the Green Climate Fund (GCF) for the 2018–2022 crediting period.

1.3. Nepal's REDD+ Journey

Nepal initiated its REDD+ process following the adoption of the Bali Action Plan at COP 13 in 2007. In 2008, Nepal joined the World Bank's Forest Carbon Partnership Facility (FCPF) and submitted a Readiness Plan Idea Note (R-PIN). By October 2009, Nepal became an observer to the UN-REDD Programme. Nepal later ratified the Paris Agreement in 2016, marking an important milestone in strengthening its commitment to REDD+. Nepal successfully implemented REDD+ readiness activities under the Readiness Fund of the World Bank's FCPF during the period 2010–2021 and formally entered the REDD+ implementation phase in 2021. Table 1 summarizes Nepal's REDD+ journey and Figure 1 presents the project area covered by the first and second REDD+ programme in Nepal under FCPF and LEAF Coalition, respectively.

Table 1: Summary of Nepal's REDD+ Journey

REDD+ initiatives	Duration	Main activities
REDD+ Readiness Project	2010-2021	The REDD+ readiness phase in Nepal focused on initiating and strengthening the institutional, policy, and technical foundations for REDD+ implementation. Key activities during this phase included the preparation of the REDD+ Readiness Preparation Proposal (R-PP), the establishment of the REDD Implementation Center, the development of Nepal's first National REDD+ Strategy (2018–2022), and the preparation of the country's first Emission Reduction Programme. This phase also emphasized the establishment of institutional arrangements for Measurement, Reporting, and Verification (MRV) and the capacity building of relevant government agencies to support the design and implementation of REDD+ policy interventions.
Nepal's first National Forest Reference Level (2000-2010)	2017	Nepal had submitted its first forest reference level (FRL) to the UNFCCC considering the reference period 2000-2010 in 2017. The technical assessment of the FRL was conducted by the secretariat in 2017 and TA report has been published in 2018.

REDD+ initiatives	Duration	Main activities
Emission Reduction Program under the FCPF of the World Bank	2018-2024	Nepal developed its first jurisdictional-scale Emission Reduction Programme Document (ERPD)[3] in 2018 as a pilot REDD+ initiative and subsequently signed an Emission Reduction Purchase Agreement (ERPA) with the World Bank in February 2021. The ERPA enables Nepal to receive results-based payments for verified emissions reductions, with a maximum ER volume of 9 $MtCO_2e$, covering two reporting periods: (i) 22 June 2018 to 31 December 2021, and (ii) 1 January 2022 to 31 December 2024. Nepal submitted its first Emissions Reductions Monitoring Report (ER-MR) for the ER Programme in 2023, covering the period June 2018 to December 2021. The report was validated and verified by the Validation and Verification Body (VVB), Aster Global Environmental Solutions, Inc., in June 2025. Following successful verification, Nepal has received its first results-based payments from the Forest Carbon Partnership Facility (FCPF) Carbon Fund under the REDD+ initiative.
ER Program under the LEAF Coalition	2022-2026	Nepal conceptualized its second jurisdictional REDD+ in 2021 and signed letter of intent with the LEAF (*Lowering Emissions by Accelerating Forest finance*) Coalition in 2021. The LEAF ER programme January 2022 after the letter of Intent[4] was signed on October 21, 2021. The LEAF ER programme intended through the LEAF Coalition, covering the entire areas of Bagmati, Gandaki, and Lumbini Provinces (36 districts), with the crediting period of 2022 to 2026. The LEAF ER program adopts the Architecture of REDD+ Transactions (ART) "The REDD+ Environmental Excellence Standard (TREES)" as its standard. Nepal has been preparing necessary technical documents showcasing historical emissions and results including TREES Registration Document (TRD) and TREES Monitoring Report (TMR) respectively. In addition, draft Benefit Sharing Plan, GRM mechanisms, Stakeholder Engagement and FPIC process, and Environmental and Social Safeguards among others are also being prepared.

1.4. Comparison with the previous submission

This document builds on Nepal's first FRL for REDD+, which was submitted to the UNFCCC and technically assessed in 2017/2018. The first FRL was prepared to demonstrate Nepal's progress in reducing deforestation and forest degradation, and enhancing forest carbon stocks, particularly in the context of the long-standing

[3] https://forestcarbonpartnership.org/system/files/documents/Nepal%20ERPD%2024May2018final_CLEAN_0.pdf
[4] https://3c5cac37-d190-41cd-8f3a-aaf6e5425bfd.usrfiles.com/ugd/3c5cac_abdccfe62d3d4693872ee80a54a8833e.pdf

implementation of community forestry (CF) as the mainstream forest management regime benefiting both forests and forest-dependent communities. The reference period for the first FRL was 2000–2010.

Nepal's current FRL has been prepared as an update of the first FRL, following a stepwise approach in accordance with UNFCCC decision 12/CP.17. As described in Section 1.2 (Objectives), the proposed FRL addresses the feedback and recommendations provided in the UNFCCC Technical Assessment Report (TAR) of Nepal's first FRL. The reference period has been revised from 2000–2010 to 2008–2017 to align with the Green Climate Fund (GCF) Results-Based Payments (RBP) crediting period of 2018–2022.

The second FRL incorporates updated activity data (AD) and emission factors (EF) generated using improved data sources and methodologies. Forest degradation, which was partially assessed using indirect methods in the first FRL, has now been fully assessed using improved methods. Collectively, these improvements enhance the completeness, transparency, consistency, and accuracy of the FRL over time. Table 2 presents a comparison of the key components of Nepal's first and second FRL submissions.

Table 2: Comparison of the First and Second FRL Submissions

Component	1st FRL (Previous Submission)	2nd FRL (This Submission)
Reference period	2000–2010	2008–2017
Activities covered	Deforestation, forest degradation from fuelwood harvesting (indirect assessment), and enhancement of carbon stocks	Deforestation, forest degradation, and enhancement of carbon stocks
Coverage	National	National
Activity Data (AD)	Wall-to-wall mapping with reference data collected using sample plots	Wall-to-wall forest cover change mapping with updated reference data using the bias-corrected area estimates
Emission Factors (EF)	Above-ground biomass (AGB) from FRA Nepal 2015 (State of Nepal's Forests)	AGB calculated from FRA field measurements conducted by FRTC during 2016–2021
Gases	CO_2	CO_2
Carbon pools	Above-ground biomass (AGB), Below-ground biomass (BGB)	Above-ground biomass (AGB), Below-ground biomass (BGB)

2. NATIONAL CONTEXT/CIRCUMSTANCES

2.1. State of forests in Nepal

National Land Cover Monitoring System (NLCMS) reported that forests (43.38%) together with other wooded land (2.70%) accounted for 46.08% of Nepal's total land area, representing a net increase of 0.75% compared to 2019 (FRTC, 2024). An increasing trend of overall forest area was reported since the community-based forest management system was implemented as the mainstream forest management regime in the country. Table 3 shows an increasing trend of overall forest cover from 44.74% (of the total country land) in 2015 to 45.31% in 2022 and 46.08% in 2024. Figure 1 highlights forest cover change between 2019 and 2022.

Table 3: Forest cover of Nepal in different periods (%)

Land Cover	LRMP 1978/79	NRSC 1984	Master Plan 1985/86	NFI 1994	FRA 2015	FRTC 2022	FRTC 2024
Forest	38.2	35.9*	37.4	29.0	40.36	41.69	43.38
Shrub	4.7	-	4.8	10.0	4.38**	3.62**	2.70**
Total	42.9	35.9	42.2	39.00	44.74	45.31	46.08

*Source: DFRS, 2015; FRTC, 2022; FRTC, 2024, *Includes some shrub area; **Other Wooded Land*

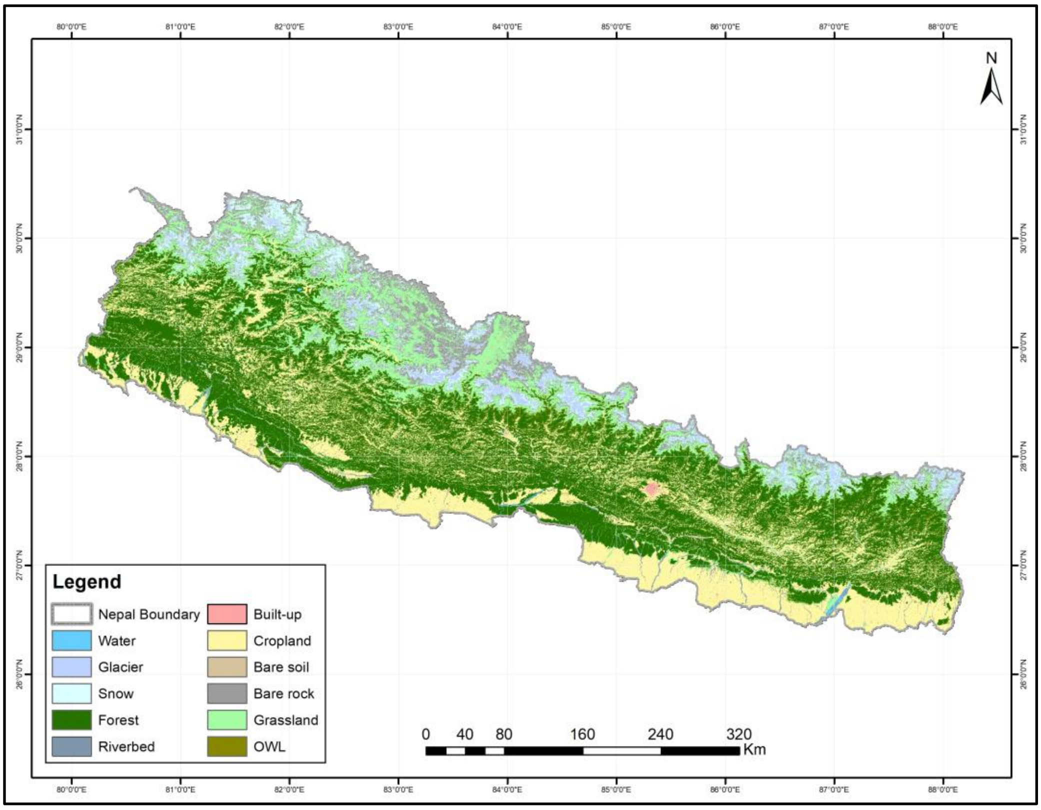

Figure 1: National Land Cover Map of Nepal, 2017

These results from the NLCMS highlight improving forest cover at the national level, while underscoring the importance of continued efforts to address localized deforestation, forest degradation, and disturbances such as forest fires and infrastructure expansion, particularly in the context of REDD+ implementation and national climate commitments. The increase in forest cover and decrease in other wooded land reflect the country's efforts towards addressing the drivers of deforestation and forest degradation.

2.2. Forest management modalities

Nepal's forests are broadly classified into two categories based on ownership and land tenure: private forests and national forests. Forests established or managed on privately owned land with legally recognized ownership documents are classified as private forests, while national forests are owned by the Government of Nepal.

National forests are managed under different forest management modalities, also referred to as management regimes, including government-managed forests, forest conservation areas, community forests, collaborative forests, leasehold forests, and religious forests. More than 35,000 community-based forest user groups are currently involved in the management of over 3.34 million ha of forests in Nepal. Of these, 23,601 Community Forest User Groups (CFUGs) manage more than 2.50 million ha of forest area nationwide (Table 4).

Table 4: Details of various forest management regimes in Nepal

SN	Forest management regime	Number	Area (ha)	Affiliated HHs
1	Community Forest	23,601	2,508,326	3,168,449
2	Collaborative Forest	31	75,654	812,870
3	Leasehold Forest (Pro-poor)	7,731	44,399	74,495
4	Leasehold Forest (Commercial)	22	640	
5	Private Forest	2,458	2,360	
6	Religious Forest	179	2,809	
7	Forest Conservation Area	11	194,156	
8	Buffer Zone Community Forest	1,067	240,870	168,071
9	Buffer Zone Leasehold Forest	88	548.7	581
10	Buffer Zone Religious Forest	7	87	
11	Forest managed by Conservation Area Management Committee	85	277,140	33,685
	Total	**35,280**	**3,346,990**	**4,258,151**

Source: National REDD+ Strategy (2025-2035) [5]

2.3. Drivers of deforestation and forest degradation

Nepal's forestry sector has long been affected by deforestation and forest degradation. The drivers of deforestation and forest degradation are largely linked to livelihood-related activities, encompassing both direct drivers and underlying causes. A preliminary assessment conducted during the preparation of Nepal's Readiness Preparation Proposal (R-PP)[6] in 2010 identified region-specific drivers of deforestation and forest degradation,

[5] National REDD+ Strategy 2025-2035, Government of Nepal. Available online at: https://redd.unfccc.int/media/national_strategy_2025_2034_redd_plus_nepal.pdf?lang=en
[6] https://www.forestcarbonpartnership.org/system/files/documents/R-PP_Nepal_revised_October.pdf

distinguishing nine types of direct drivers, as well as indirect drivers, including socio-economic factors such as population growth and poverty. These drivers and their underlying causes are further elaborated in Nepal's National REDD+ Strategy (2025–2035). Table 5 summarizes the major drivers of deforestation and forest degradation identified during the preparation of the National REDD+ Strategy (2025–2035). For preparing this FRL, forest change was verified using FAO's Collect Earth Online, integrating Google Earth Engine indices and historical imageries. Therefore, other drivers of degradation, e.g., rapid spread of invasive alien species and mining and excavation could not be considered as they cannot be reliably distinguished in imageries.

Table 5: Drivers of deforestation and forest degradation and underlying causes

Drivers identified	Underlying causes
• Haphazard and unplanned infrastructure development • Agriculture expansion • Human settlement and urban expansion • Frequent forest fires • Unregulated rural road construction • Mining and excavation (stone, sand, and boulder) • Illegal and unsustainable Forest products extraction • Unregulated livestock grazing • Rapid spread of invasive alien species • Flooding • Landslide	• Demographic factors: migration and population growth in specific areas • Governance-related factors: Weak law enforcement (EIA, IEE, and monitoring), High political interferences, & lack of political commitment. • Policy & institutional factors: Inconsistent sector & cross-sector policy & legal provisions, weak coordination among forestry (within) & non forestry authorities. • Socio-economic factors: High Forest product demand, high forest dependency, limited livelihood options, decreasing collective actions. • Climate Change: Prolonged drought leading to increased and intense forest fires incidences, extreme rainfall leading to floods and landslides.

Source: National REDD+ Strategy (2025-2035)

2.4. REDD+ relevant policies and plans

Nepal has established a comprehensive policy, legal, and institutional framework that enables the implementation of REDD+ and forest-based climate change mitigation. Key policies, strategies, and legal instruments relevant to REDD+ implementation are summarized below.

Constitution of Nepal[7]

Following the promulgation of the Constitution of Nepal in 2015, the country adopted a three-tier federal governance system comprising federal, provincial, and local governments. Article 57(1) and Schedule 5 (27) of the Constitution identify carbon services as a matter under federal jurisdiction, thereby placing responsibility for forest

[7] https://www.moljpa.gov.np/public/uploads/238f7219-492b-40af-a919-c94c35f9c269.pdf

carbon management, including REDD+, with the Government of Nepal.

Sixteenth Periodic Plan (16th Plan)[8]

The Sixteenth Periodic Plan emphasizes transformative strategies related to biodiversity conservation, climate change mitigation, and the green economy. The Plan promotes enhanced forest carbon stocks through sustainable forest management, assisted natural regeneration, and reforestation, alongside incentives for low-carbon and emission-reducing technologies. It also highlights the importance of carbon trading as a mechanism to generate economic and environmental benefits.

National Forest Policy 2019[9]

The National Forest Policy (2019) recognizes forest-based emission reduction initiatives, including REDD+, as a key approach for achieving national emission reduction targets. This policy builds on Nepal's earlier commitments articulated in the National Forestry Policy (2015). Section 8.5 explicitly addresses environmental services, including REDD+ and forest carbon initiatives.

National REDD+ Strategy (2025-2035)[10]

The National REDD+ Strategy (2018-2022) approved in April 2018, focuses on five main objectives: reducing emissions and enhancing carbon storage through sustainable forest management; ensuring fair resource tenure and benefit sharing; improving livelihoods and employment for forest-dependent groups, especially marginalized communities; aligning policies and legal frameworks with national and global standards to promote governance, gender equity, and social inclusion; and strengthening forest monitoring systems for effective measurement and reporting. The National REDD+ Strategy (2025-2035)[11] has been developed after assessing the previous strategy's progress, gaps, and challenges, with an emphasis on identifying new priorities. Drawing on lessons learned, this updated strategy offers a framework to implement results-based REDD+ and forest emission reduction in response to evolving international and national contexts. It aims to expand Nepal's role in global climate mitigation by broadening REDD+ and related Emission Reduction Programs within the Paris Agreement's market and non-market mechanisms through its interrelated six objectives, 10 strategies, and a total of 69 priority actions thereunder.

National Climate Change Policy 2019[12]

The National Climate Change Policy (2019) recognizes REDD+ as a strategic instrument for forest-based climate change mitigation by addressing the drivers of deforestation and

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[8] https://www.npc.gov.np/content/6462/the-sixteenth-plan--fical-year-2024-25-2028-29-/

[9] https://www.mofe.gov.np/content/33/national-forest-policy--2075/

[10] https://forestcarbonpartnership.org/system/files/documents/Nepal%20National%20REDD%2B%20Strategy.pdf

[11] https://redd.unfccc.int/media/national_strategy_2025_2034_redd_plus_nepal.pdf

[12] https://www.mofe.gov.np/content/37/national-climate-change-policy--2076--2019-/

forest degradation. The policy also emphasizes the mobilization of climate finance through results-based payments to strengthen ecosystem resilience and support local livelihoods. It mandates equitable benefit sharing, with at least 80 percent of REDD+ and similar benefits allocated to communities.

Environment Protection Act, 2019[13]

The Environment Protection Act (2019), under Article 28, authorizes the Government of Nepal to participate in carbon trading mechanisms established under international treaties for emission reduction and enhancement of carbon stocks.

Forest Act ,2019[14] and Forest Regulations, 2022[15]

The Forest Act (2019) and Forest Regulations (2022) provide the legal basis and operational mechanisms for REDD+ implementation in Nepal, in line with the National Forest Policy (2019) and the National Climate Change Policy (2019). The Forest Act includes provisions for forest carbon trading and benefit distribution through the Forest Development Fund (Article 44(a) and (b)). The Forest Regulations further elaborate procedures for emission reduction program development (Rule 107), free, prior, and informed consent (FPIC) (Rule 107(6)), and carbon benefit sharing and decision-making processes through the Forest Development Fund (Rules 107(7–8) and 115).

Nationally Determined Contribution (NDC)-3[16]

Nepal's Third Nationally Determined Contribution (NDC-3), approved in May 2025, outlines policies and measures to achieve national emission reduction targets. In the forestry sector, it prioritizes updating national forest area data by 2035, strengthening forest monitoring systems, and enhancing participation in carbon markets through the REDD Implementation Centre, in coordination with the Forest Research and Training Centre.

Long-term Strategy for Net Zero Emissions, 2021[17]

Nepal's Long-term Strategy for Net-Zero Emissions identifies the forestry sector as a key contributor to achieving net-zero emissions. Core strategies include reducing deforestation, expanding forest areas through afforestation and reforestation, minimizing forest degradation while improving forest health, and promoting sustainable forest management practices.

Carbon Trading Regulations, 2025

[13] https://www.moljpa.gov.np/public/uploads/c2dde580-93de-457c-bff4-8c93a82561fe.pdf
[14] https://www.moljpa.gov.np/public/uploads/c87668b1-3d60-4849-8e71-2bd1e2500cd2.pdf
[15] https://www.mofe.gov.np/content/67/forest-rules--2079/
[16] https://unfccc.int/sites/default/files/2025-05/Nepal%20NDC3.pdf
[17] https://unfccc.int/sites/default/files/resource/NepalLTLEDS.pdf

The Government of Nepal has recently approved the Carbon Trading Regulations, 2025, establishing a comprehensive legal framework for the development and implementation of emissions reduction projects. Under these Regulations, government agencies, state-owned institutions, business organizations, and private sector entities are authorized to implement carbon reduction projects by following a defined procedural pathway. Project proponents are permitted to directly enter into agreements with third parties for carbon trading, with the Government acting primarily as a facilitator. Schedule 1 of the Regulations specifies the eligible areas and sectors for the development of Emissions Reduction Projects, including the Agriculture, Forestry and Other Land Use (AFOLU) sector (Schedule 1.3).

3. ELEMENTS OF NEPAL'S FRL

3.1. Forest definition

Decision 12/CP.17 requires Parties to provide the definition of forest used in the construction of forest reference emission levels and/or forest reference levels and, where applicable, to explain any differences with definitions used in the national greenhouse gas inventory or reporting to other international organizations.

Land cover definitions applied in the national FRA follow FAO recommendations and are based on minimum area, minimum canopy cover, and minimum potential tree height. In Nepal, the forest definition used for the national FRA is fully consistent with the FAO forest definition. This definition has therefore been adopted for the construction of Nepal's FRL to ensure consistency, transparency, and comparability of activity data and emission and removal estimates.

The forest definition used for the development of Nepal's FRL is as follows:
"Forest is land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use"(FAO, 2015).

This definition is consistent with that used in the previous FRL, National Forest Monitoring System (NFMS), and is also aligned with the forest definition applied in the national greenhouse gas inventory for the LULUCF sector. As a result, there are no inconsistencies among the forest definitions used in the FRL, FRA, NFMS, NLCMS and in other national and international reporting, ensuring methodological consistency across REDD+ implementation, greenhouse gas inventory reporting and results-based payment frameworks.

3.2. Historical data / Historical reference period

This Forest Reference Level (FRL) was developed based on historical emissions and removals over a 10-year reference period from January 2008 to December 2017. Although the UNFCCC has not explicitly defined the length of the historical period for FRL construction, Nepal has adopted a period of 10 years for its FRL preparation, suggested by the GCF policy for the result-based payments for REDD+ performance. The reference period applied for this current FRL is 2008–2017. This represents a revision from the 2000–2010 reference period used in Nepal's first FRL submission, to align with the GCF Results-Based Payments (RBP) crediting period of 2018–2022. The FRL is projected over a subsequent five-year period (2018–2022) to enable comparison of projected reference emissions with actual emissions during the results period.

3.3. REDD+ activities

The proposed FRL includes the following REDD+ activities among the five activities that are included in paragraph 70 of decision 1/CP.16:

a) Reducing emissions from deforestation,
b) Reducing emissions from forest degradation, and

c) Enhancement of forest carbon stocks (reforestation/afforestation)

In the context of Nepal's FRL, deforestation, forest degradation and enhancement of forest carbon stocks are defined as follows:

3.3.1. Deforestation

Deforestation is the long-term or permanent conversion of forest to other (non-forest) land use.

3.3.2. Forest Degradation

Degradation is the long-term or permanent reduction of biomass in the forest land. The expression "long-term" is used in opposition to short-term/temporary degradation, which may be induced by individual disturbance and from which we can assume that the forest will be able to recover, thus over time resulting in no net change to CO_2 in the atmosphere. Long-term degradation is understood as the result of recurrent disturbance with an impact above the recovery capacity of the forest, thus resulting in emissions of CO_2 to the atmosphere which is not compensated by subsequent removals through post-harvest regrowth.

For instance, disturbances adequately spaced over time, such as fuelwood harvesting or livestock grazing, do not induce long-term or permanent degradation, while recurrent/continued harvesting and/or grazing above the regrowth capacity of the forest cause the progressive reduction of the forest biomass and other negative impacts that will worsen until the excessive harvesting and/or grazing is reduced or stopped. Degradation may be considered permanent when the recovery capacity of the forest to return to its original status is impeded, as in case of a critical loss of soil and nutrients. We could refer to the actual emissions associated at the time of the degrading event (e.g. fuelwood extraction) as gross degradation. Net degradation deducts removals associated with the forest recovery processes following the degradation event (e.g. post-harvest regrowth). As such, gross degradation emissions can be much higher than net degradation emissions. Nepal reports net degradation in this FRL.

3.3.3. Enhancement of forest carbon stock

Enhancement of forest carbon stock, for the purposes of the FRL, is the positive complement to deforestation and refers to the long-term or permanent conversion of non-forest land use categories to forest through afforestation/reforestation/restoration activities. CBFM practices, particularly CF and pro-poor Leasehold Forestry programs, are considered to contribute significantly to reforestation/afforestation/restoration.

3.3.4. Rationale for inclusion of the above activities

Deforestation and forest degradation are the main sources of emissions from the forestry sector in Nepal. Currently, deforestation is a problem in small pockets, often driven by haphazard infrastructure development and encroachment for farming and settlement. On the other hand, forest degradation remains a persistent challenge in many landscapes, because of increasing forest fire incidents, uncontrolled grazing and increased population pressure on land and timber resources.

Afforestation/reforestation and participatory management of forest resources have contributed to increased/restoration of the forest cover in Nepal. Measurement of the outcomes of these three activities (i) reducing deforestation, (ii) reducing forest degradation, and (iii) promoting afforestation, reforestation (enhancement of forest carbon stocks) enables Nepal to assess the contribution of the forest sector to emissions reduction and enhancement of carbon stock. While CF contributes to positive outcomes of these three activities, it is also believed to contribute substantially to the other activities sustainable management of forest and conservation of forest carbon stock in forest land remaining forest land.

Activities like sustainable management of forest and conservation of forest carbon stocks in forest land remaining forest land may constitute a significant share of removals, especially thanks to Nepal's efforts in promoting community forestry. However, due to the data and methodological constraints Nepal is not yet able to include such activities in forest land remaining forest land.

3.4. Pools included

Decision 12/CP.17 (Annex C) specifies that forest reference emission levels and/or forest reference levels should not exclude significant carbon pools and requires Parties to provide transparent and complete justification for the omission of any pool.

In line with this decision, Nepal assessed the relevance of all five IPCC forest carbon pools for inclusion in the construction of the FRL. Nepal considers that valid reasons for the omission of a carbon pool include: (a) the pool represents a very small proportion of total emissions or removals, (b) the costs of data collection and analysis exceed the expected benefits of including the pool, even if the pool may be significant, (c) no credible data are available or can reasonably be generated, and (d) available information indicates that, despite being significant in absolute terms, the pool is not expected to change materially during the monitoring period and therefore does not contribute significantly to emissions or removals.

Taking these criteria into account, and in accordance with Decision 12/CP.17 (Annex C), the proposed FRL includes the following forest carbon pools:

- Above-ground biomass
- Below-ground biomass

The remaining carbon pools dead wood, litter and soil organic carbon have been assessed and excluded from the FRL for the reasons outlined below.

Evidence from *The State of Nepal's Forests 2015* indicates that litter and dead wood together contribute approximately 1.19 t C ha^{-1}, compared to an average above-ground forest biomass stock of 108.88 t C ha^{-1}. This demonstrates that dead organic matter (DOM) represents a very small proportion of total forest carbon stocks. Consistent with FRA data, DOM accounts for less than 5 percent of total forest carbon in Nepal. In line with IPCC guidance, which considers carbon pools contributing approximately 25–30 percent or more of total carbon stocks to be significant, dead wood and litter are therefore considered not significant in the context of Nepal's FRL and have been excluded.

Soil organic carbon (SOC) has been omitted due to the absence of credible, country-specific data and because the cost and effort required to generate such data would outweigh the expected benefits of inclusion at this stage. Furthermore, the estimation of SOC emissions and removals following land-use change requires, at a minimum, information on the post-conversion land-use category and associated management regime (IPCC 2006 Guidelines, Volume 4, Section 2.3.3.1). Such information is currently not available in Nepal in a form that would allow reliable estimation of SOC changes.

In addition, expert judgment indicates that SOC is unlikely to contribute significantly to emissions or removals in Nepal's forest sector, as there is no drainage of peatlands and forest soils are generally stable. Consequently, SOC is assessed as a non-significant pool for the purposes of this FRL.

The exclusion of dead wood, litter and soil organic carbon is therefore considered conservative and consistent with the requirements of Decision 12/CP.17 (Annex C), the IPCC 2006 Guidelines, and the stepwise approach to improving methodological completeness over time.

3.5. Gases included

For the estimation of Nepal's FRL, only a major greenhouse gas, carbon dioxide (CO_2), has been considered. Non-CO_2 gases, including carbon monoxide (CO), methane (CH_4), and nitrous oxide (N_2O), have not been assessed and excluded. Flooded lands may emit CH_4 and N_2O in significant quantities depending on factors such as prior land use, climate, age of flooding, and management practices (IPCC, 2006a). Emissions of CH_4 and N_2O are also known to occur in mangrove areas. Nepal has no coastline, and therefore, no mangroves or seasonally/permanently flooded forest areas exist. Consequently, emissions of CH_4 and N_2O from organic or mineral soils associated with forestry management activities, such as extraction, drainage, rewetting, or revegetation (IPCC, 2014), are not relevant.

Experience under the Kyoto Protocol's Clean Development Mechanism (CDM) and FCPF Decision Support Tool Part 1 suggests that emissions from fertilizer use, or planting of leguminous species, are not significant. A large proportion of CH_4 emissions in Nepal originates from enteric fermentation, solid waste disposal, wastewater treatment, and rice cultivation, as reported in Nepal's Initial National Communication, 2004. However, these sources are not associated with forestry activities and are therefore outside the scope of the FRL.

Forest fires in Nepal are generally more frequent outside forests than within. Reliable national data on forest-fire-affected areas and biomass loss are limited. The Global Forest

Resources Assessment 2015 (FAO, 2016) estimates an average of 9,738 ha/yr of burned forest for 2003–2010, primarily affecting forest remaining forest land. Afforestation and reforestation activities in Nepal occur on non-forest lands and are not preceded by burning.

While preparing the first FRL, Nepal applied IPCC default methods to estimate non-CO_2 emissions from forest fires, using burned forest area data from FAO (2015) and average above-ground biomass from the National Forest Inventory (2010-2014) as the mass of fuel for combustion. This approach indicated that non-CO_2 emissions from forest fires contributed approximately 22% of total annual emissions included in the FRL.

However, this estimate was considered to overstate actual non-CO_2 emissions for two main reasons:

1. Overestimation of burned area: Fires in Nepal's forests are generally scattered. The burned areas reported by FAO (2015) were derived from the MODIS Collection 5 Burned Area Product, which has a pixel size of 250 m. This resolution can substantially overestimate the actual burned area when fire-affected patches are smaller than 250 × 250 m (Van Lierop et al., 2015).
2. Mismatch in biomass values: Forest fires predominantly affect degraded and secondary forests with lower above-ground biomass, whereas the initial calculation used average biomass representative of primary or dense forests. Using IPCC default fuel biomass consumption values for secondary forests (IPCC, 2006a) (Table 2.4) would reduce the estimated non-CO_2 emissions by approximately 40%, lowering the contribution to around 13% of total FRL emissions. Considering the likely overestimation of burned areas by MODIS, the actual contribution is probably less than 10% of total annual emissions included in the FRL.

Based on this assessment, Nepal concludes that non-CO_2 emissions from forest fires are insignificant. Furthermore, due to the lack of reliable fire data, it has been decided to omit non-CO_2 gases associated with fires from the FRL calculation. The excluded greenhouse gases, therefore, include CO, CH_4, and N_2O for the following reasons:

- Nepal has no mangroves.
- There are no seasonally or permanently flooded forest areas in the country.
- Forest fires are not a significant source of emissions in the forestry sector.

This approach is consistent with IPCC 2006 Guidelines, the stepwise approach for FRL development, and UNFCCC decision 12/CP.17, ensuring that only significant sources of emissions are included in the FRL.

3.6. Scope and scale

Under this submission, Nepal's proposed FRL is reported at the national level. According to UNFCCC decision 12/CP.17, countries should aim to implement REDD+ at the national level but may implement it at sub-national level as an interim measure if necessary. Advantages of implementing at national level are to avoid internal displacement of emissions and to ensure that the impact of national policies and measures can be properly assessed. Critical datasets are available at national level to support national level FRL assessment. Nepal carried out a National Forest Inventory (NFI) between 2010 and 2014, temporal land cover maps generated with national coverage and related national level ancillary databases.

3.7. Consistency with the national GHG inventory

The proposed FRL is fully consistent with Nepal's national GHG inventory for the LULUCF sector. Both documents have used the same data sources: NFI, NFMS, satellite-based forest cover analysis i.e. NLCMS, carbon pools, forest definition (>0.5 ha, >5 m height, >10% canopy cover), and IPCC-compliant methods for estimating emissions and removals. Activities included in both the inventory and the FRL comprise deforestation, forest degradation, and afforestation/reforestation. CO_2 is the common GHG measured in both reports. Non-CO_2 emissions from fires are omitted in the FRL for the reasons described above in section 3.5. This consistency ensures comparability over time, transparency, and methodological coherence, providing a reliable benchmark for REDD+ results-based reporting. The stepwise approach applied allows for the future inclusion of additional pools or gases as improved data and methodologies become available. Overall, the FRL conservatively reflects Nepal's forestry emissions and removals while remaining fully aligned with the national GHG inventory.

The proposed FRL has been developed to align with UNFCCC guidance while building on improvements identified since the first FRL submission. The FRL is grounded in the IPCC 2006 Guidelines, similar to the methodology used in the forestry sector of the National GHG Inventory (GHGI) reported in the Third National Communication 2021 (NC3)[18] and the First Biennial Report 2025 (BTR1)[19]. This ensures fundamental methodological compatibility, while the second FRL incorporates updated country-specific data (AD) and refined emission factors (EF).

The GHGI LULUCF sector in the TNC and BTR covers key activities including forest management, deforestation, and afforestation/reforestation, with estimates largely based on FAO statistics, national forest statistics, and IPCC default emission factors. In comparison, this FRL integrates NFI data, satellite-derived activity data, and improved biomass estimates to refine CO_2 emissions.

Carbon pool coverage in this FRL aligns with the GHGI (LULUCF sector), encompassing above-ground and below-ground biomass. Methodologically, while both approaches follow IPCC guidance, the FRL applies direct measurement and country-specific emission factors where available, resulting in more accurate and lower-uncertainty estimates.

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[18] unfccc.int/sites/default/files/resource/TNC Nepal_Final_v2.pdf
[19] unfccc.int/sites/default/files/resource/Nepal_First_BTR.pdf

In summary, this FRL proposal and the GHGI LULUCF sector are methodologically consistent, sharing a common IPCC-based framework, activity definitions, and carbon pools. The FRL represents an improvement over earlier inventory estimates through the use of updated data and refined emission factors, ensuring greater precision for REDD+ reporting and UNFCCC compliance.

4. ACTIVITY DATA

4.1. Approach

The total land area, including changes between change-categories, was estimated adopting the IPCC approach 2 of land representation in GHG emission estimation. Spatially explicit location map of the land-use conversions/changes between or within the forest and non-forest categories were tracked by preparing the forest cover change map. However, the estimates of activity data were derived from the bias-corrected area calculation approach.

4.2. Time series Land-use change, and a sample-based unbiased area estimation approach

Land-use change, and a sample-based unbiased area estimation method were used for the second FRL (2008–2017) of Nepal to estimate emissions and removals from forest-related land-use change. The analysis used Landsat satellite imagery with a spatial resolution of 30 meters, and Land cover maps developed under the National Land Cover Monitoring System were also used as the primary input data. Time-series analysis was carried out using the LandTrendr algorithm within the Google Earth Engine cloud computing platform. This approach allowed consistent detection of forest cover change over the period 2008-2017.

Forest cover change was classified into five strata: *Stable Forest, Forest Degradation, Deforestation, Stable Non-Forest, and Forest Enhancement.* Stable Forest represents areas that remained forest throughout the period. Forest Degradation includes areas where forest cover persisted, but canopy conditions declined. Deforestation represents the conversion of forest to non-forest land. Stable non-forest includes areas that remained non-forest. Forest Enhancement represents areas converted from non-forest to forest land.

Sample plots were allocated proportionately across the five strata randomly. Visual interpretation of these samples was conducted using FAO's Collect Earth Online, integrating Google Earth Engine indices, historical imagery, and Bing Maps for IPCC-compliant assessments. The stratified change map and interpretation results were used for accuracy assessment and unbiased area estimation. The second FRL methodology is more robust than the first FRL (2000-2010) submitted in 2017 (Table 6).

Table 6: Methodology used in First and Second FRL

Aspect	**First FRL (2000-2010)**	**Proposed Second FRL (2008-2017)**
Reference period	2000-2010	2008-2017
Spatial scale	National	National
Satellite data	Landsat TM and ETM+ (30 m)	Landsat time series (30 m)
Mapping platform	Desktop processing	Google Earth Engine (cloud-based)

Land cover source	ICIMOD land cover maps for 2000 and 2010	NLCMS
Change detection approach	Bi-temporal land cover comparison	Time-series analysis using LandTrendr
Forest change classes	Forest / Non-forest change focus	Five strata: Stable Forest, Degradation, Deforestation, Stable Non-Forest, Enhancement
Degradation mapping	Proxy-based (fuelwood extraction using WISDOM)	Spatially explicit degradation class from time-series analysis
Stratification	4 strata (forest loss, forest gain, stable forest, stable non-forest)	5 strata based on mapped change processes
Sampling design	Stratified random sampling	Stratified random sampling
Sample allocation	Fixed number, stratified by change and physiographic region	Proportional allocation across five strata
Reference data source	Google Earth, Landsat, limited field data	Collect Earth Online with Google Earth, Landsat time series, and Sentinel 2 and other high resolution images
Reference data tool	Collect Earth (desktop)	Collect Earth Online (web-based)
Area estimation	Bias-corrected area estimates	Bias-corrected area estimates using 3600 reference data plots
Uncertainty reporting	Confidence intervals reported	Confidence intervals reported of all of the estimated using Olofsson et al. 2014 good practice guidelines / Monte Carlo simulations.
Key improvement	First national FRL using best available data	Improved temporal consistency, automation, and national system alignment

4.3. Methodology

4.3.1. Land cover mapping

Second FRL 2008-2017 used the land cover map of 2008 and 2017 developed by NLCMS of Nepal. Forest Research and Training Centre (FRTC) has developed NLCMS to produce an annual land cover map of Nepal with technical assistance from ICIMOD. Altogether 11 land cover classes have been identified after consultations with stakeholders during the development of NLCMS. The Land cover classes are Forest, Other wooded land (OWL), Grassland, Cropland, Built-up area, Water body, Riverbed, Bare soil, Bare rock, Snow, and Glacier. Based on NLCMS, FRTC published land cover maps from 2000 to 2022.

Figure 2 presents the methodology used for NLCMS. Land cover maps have been prepared by using 46,000 reference sample data, Landsat 5, 7 and 8 images, and other additional layers such as Digital Elevation Model (DEM), tree canopy height, and tree canopy cover data which were provided by the Global Land Analysis and Discovery lab (GLAD) of the University of Maryland (UMD). Similarly, the glaciers and glacial lakes data were generated by ICIMOD and built-up area layers and nighttime light data layers were sourced from Open Street Map (OSM) and National Oceanic and Atmospheric Administration (NOAA), respectively. The steps, such as image pre-processing, preparation of covariates, utilization of supervised machine learning algorithm (Random Forest) for primitive generation, temporal smoothing, and assemblage, were performed on the Google Earth Engine cloud computational platform.

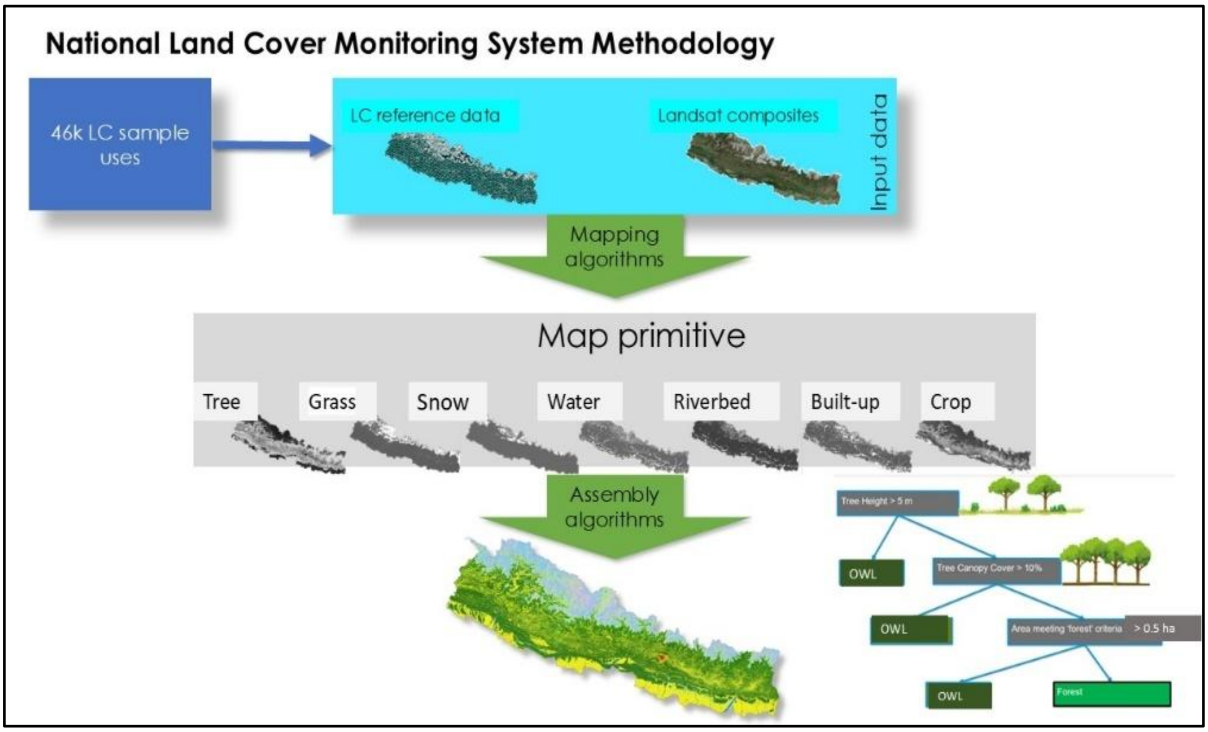


Figure 2: National Land Cover Monitoring System Methodology

NLCMS methodology follows an eight-step workflow. It begins by defining the classification scheme and collecting training samples, then processing Landsat imagery into annual composites. These are combined with thematic data and spectral indices to create input layers for supervised machine learning, which produces provisional land cover maps. These "primitives" are refined by integrating tree canopy and height data, then customized using a decision-tree logic to generate the final maps, which undergo rigorous accuracy validation. The full systematic process is depicted in Figure 3.

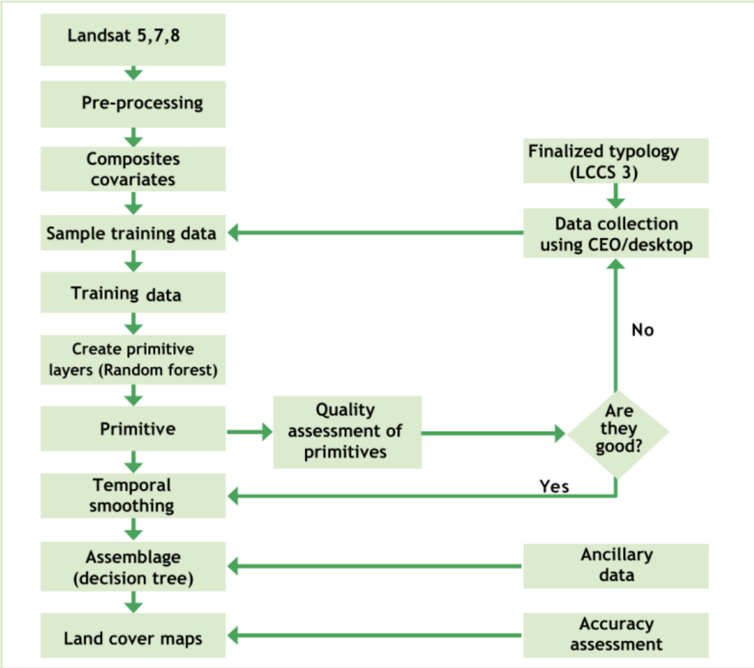


Figure 3: Detailed National Land Cover Monitoring System Methodology

4.3.2. Time series land use change by LandTrendr algorithm

LandTrendr stands for *Landsat-based Detection of Trends in Disturbance and Recovery*. It is an algorithm that uses long-term satellite data (especially from Landsat) to map and track changes on the land surface over time. It is widely used in forest and land monitoring systems, including MRV frameworks. The main goal is to detect where and when major changes occur on the land surface, such as a disturbance event or a recovery process.

Here, we applied the Nepal Forest Change Area Estimation Tool, developed by the Spatial Informatics Group (SIG) for REDD+ activities. This is a web-based tool designed to support forest change assessment. It has direct links to a Google Earth Engine repository that supports forest change mapping tasks. The repository provides a graphical user interface that allows users to run LandTrendr and other algorithms in a simple and consistent way. The Standard Operating Procedure to run LandTrendr is also available in Google Doc.

It takes a stack of yearly satellite images (for example, one composite per year) and analyzes the spectral (reflectance) values of each pixel through time.

How LandTrendr Works

LandTrendr analyzes long-term satellite image time series to detect land surface changes such as forest disturbance and recovery. It is based on the idea that vegetation change alters spectral reflectance patterns over time, and these patterns can be separated from noise through temporal segmentation.

1. Time-series construction

Annual Landsat image composites are created for a defined seasonal window to reduce cloud and phenology effects. Each pixel forms a yearly spectral trajectory using vegetation-sensitive indices such as NBR, NDVI, or Tasseled Cap Wetness.

2. Temporal segmentation

For each pixel, LandTrendr fits a set of straight-line segments to the spectral time series. This process reduces year-to-year noise caused by atmosphere, sensor differences, and acquisition timing, while preserving the underlying trend. The segmentation identifies breakpoints (vertices) that mark the start or end of disturbance or recovery events.

3. Model fitting and parameter control

The algorithm applies constraints such as maximum number of segments, recovery thresholds, and statistical significance limits to avoid overfitting. These parameters control how abrupt or gradual changes are detected and help balance the sensitivity and stability of results.

4. Change detection outputs

From the fitted segments, LandTrendr derives key change metrics, including:

- Year of disturbance (YOD)
- Magnitude of change (MAG)
- Duration of change (DUR)
- Pre-disturbance spectral value (PREVAL)

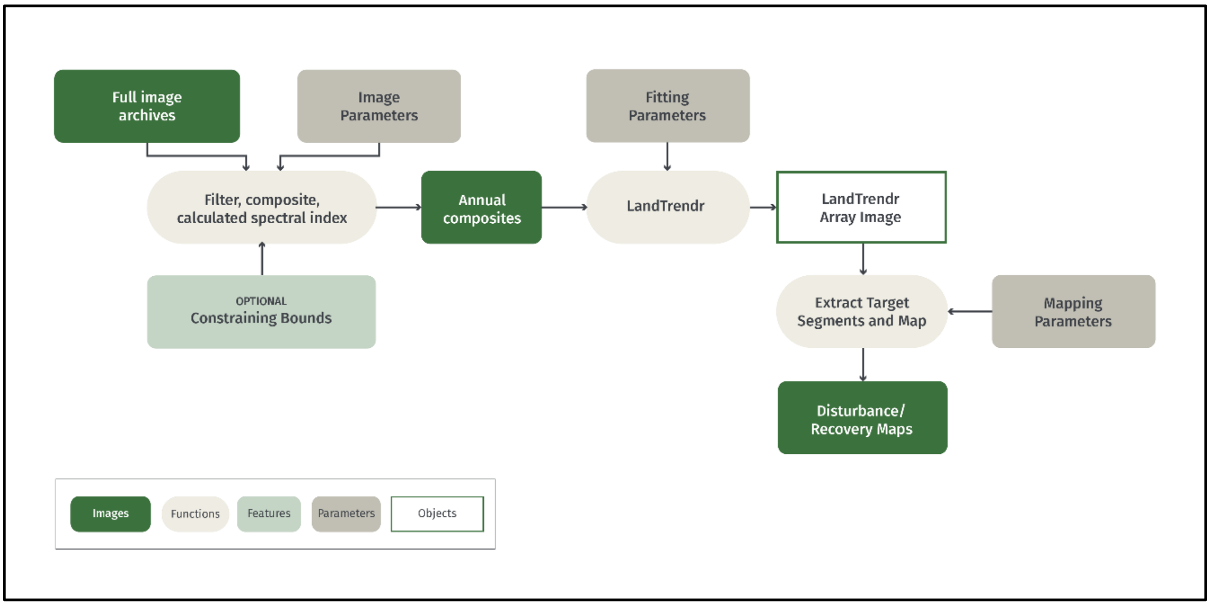
These metrics describe when the change occurred, how strong it was, and how long it lasted.

5. Loss and gain mapping

Forest loss (deforestation and degradation) and forest gain (regrowth and restoration) are mapped separately using different filtering rules. Loss focuses on the greatest negative change, while gain focuses on the most recent positive change.

6. Post-processing and map assembly

Loss and gain maps are post-processed and combined into a single forest change strata map. Each pixel is assigned a final change class, ensuring that gain and loss do not overlap and that forest dynamics are consistently represented. Final map has 5 strata Stable Forest (1), Forest Degradation (2), Deforestation (3), Stable Non-forest (4), and Forest Enhancement (5). Figure 4 presents LandTrendr algorithms in GEE steps.



Source: https://openmrv.org/web/guest/w/modules/mrv/modules_2/landtrendr#14-landtrendr-application

Figure 4: Overall Methodology of LandTrendr

4.3.3. Sample Design and Reference data collection

Visual interpretation of reference data against the map data was used to calculate the unbiased area estimates of the stable and land use change classes for the activity data. Unbiased area estimation method was derived from the procedure proposed by Olofsson's good practice guidelines. Reference sample points were first selected using an area-proportional approach. Additional emphasis was then given to forest degradation, deforestation, and forest gain. A total of 3,600 reference samples were randomly allocated considering the change class and physiographic regions to increase the accuracy of forest change area estimation. Visual interpretation was carried out using Collect Earth Online, a free and open-source tool for viewing and interpreting high-resolution satellite imagery. The tool supports efficient collection of current environmental information and allows users to observe land changes over time. Before visual interpretation began, an interpretation logic and Interpretation key were developed, and interpreters were trained accordingly. The reference data collection methodology in Collect Earth Online is given in ANNEX 1.

4.3.4. Unbiased Area estimation and Uncertainty Analysis of Activity data

Maps derived from satellite imagery often contain inaccuracies due to classification errors. Unbiased area estimation and uncertainty analysis have gained greater importance in carbon accounting and are also emphasised by IPCC guidelines and Methods and Guidance from the Global Forest Observations Initiative (MGD 3.0). For this FRL, the error matrix was prepared using the map classification information and reference data were collected from randomly generated sample plots using Collect Earth Online. Three thousand six hundred (3600) randomly generated sample plots were visually interpreted using high-resolution images to calculate the error matrix. Based on this matrix, overall accuracy, producer's accuracy, and user's accuracy were calculated for the final map strata (Stable Forest, Forest Degradation, Deforestation, Stable Non-forest, and Forest Enhancement). Unbiased area estimation was carried out following the good practice guidelines described by Olofsson et al. (2014). Area estimates were derived by combining the map-based area proportions with the reference sample proportions obtained from the error matrix. This approach corrects classification bias and provides statistically robust area estimates. Unbiased area estimates and their associated accuracies were produced at both the national level and for each physiographic region.

5. EMISSION FACTORS

5.1. Stratification

The study adopted the five physiographic regions (Figure 5), as defined by the Department of Survey, for stratification to analyze and report the results. These physiographic strata are widely used across Nepal for national and sub-national assessments. A brief description of each physiographic region is presented below.

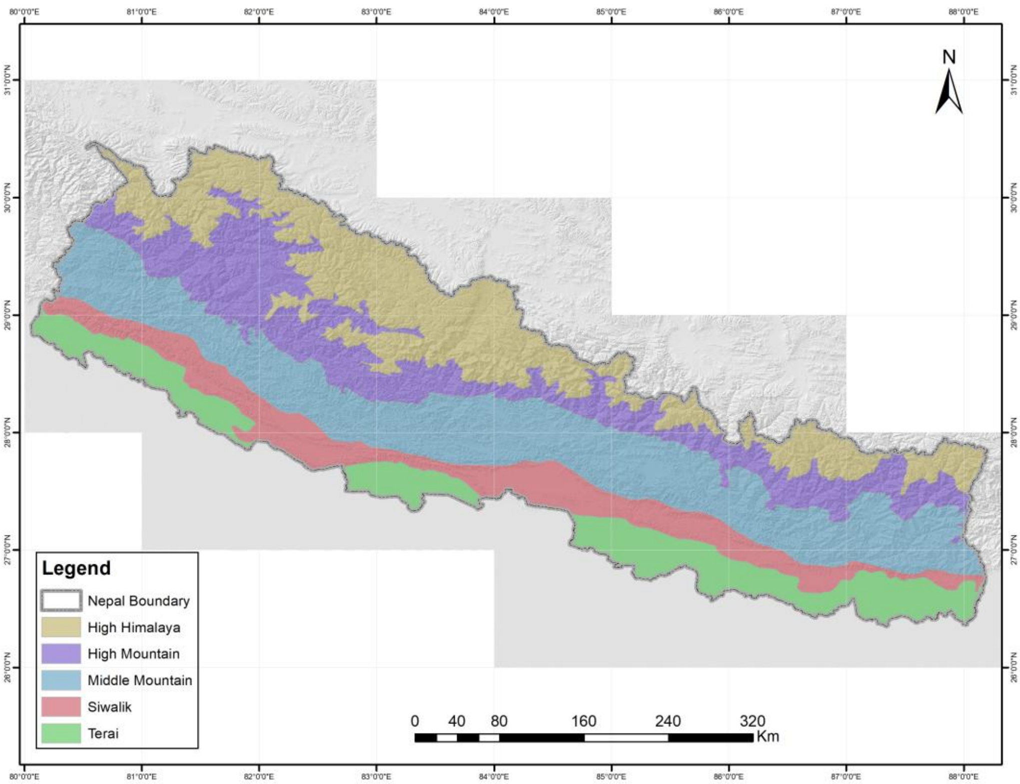


Figure 5: Physiographic regions of Nepal

5.1.1. Terai

The Terai physiographic region occupies approximately 13.7% of Nepal's total land area. Geomorphologically, it consists of gently sloping recent and post-Pleistocene alluvial deposits forming a piedmont plain south ofthe Himalayas. The elevation of the Terai ranges from 63 m to 330 m above mean sea level (LRMP, 1986).

5.1.2. Churia[20]

The Churia region is the youngest mountain range in the Himalayas. Located immediately north of the Terai, it extends across southern Nepal from east to west, skirting the southern flanks of the Himalayas. The region covers about 12.8% of the country's total land area and spans parts of 37 districts (DoS, 2001). Elevation in the Churia region ranges

[20] **Siwalik and Churia have been used interchangeably in this document.**

from 93 m to 1,955 m above mean sea level.

5.1.3. Middle Mountains

The Middle Mountains region lies north of the Churia along the southern flanks of the Himalayas. It occupies about 29.2% of Nepal's total land area and includes parts of 56 districts. The elevation ranges from approximately 110 m in the lower river valleys to 3,300 m above mean sea level.

5.1.4. High Mountains

The High Mountains region covers about 20.4% of the country's total land area and spans parts of 40 districts. Elevation in this region ranges from 543 m in river valley floors to 4,951 m above mean sea level. The landscape is characterized by rugged terrain and very steep slopes.

5.1.5. High Himal

The High Himal region includes the highest Himalayan massifs and occupies about 23.9% of Nepal's total land area. It covers parts of 25 districts, with elevations ranging from 1,960 m to 8,848 m above mean sea level.

5.2. Description and Analysis of NFI for Biomass Estimation

The Government of Nepal, through the FRTC under the Ministry of Forests and Environment, implemented the FRA Nepal during the period 2010–2014 with technical and financial support from the Government of Finland. The FRA Nepal established a comprehensive National Forest Inventory system that provides nationally consistent and statistically robust information on forest area, growing stock, biomass, emission factors, and forest carbon stocks. The assessment produced a national synthesis report as well as detailed physiographic region–wise reports for the Terai, Churia, and Middle Mountains, along with a combined report for the High Mountains and High Himal regions, documenting region-specific methodologies and results.

Building on the FRA Nepal framework, the Government of Nepal has institutionalized a continuous national forest monitoring system based on the remeasurement of permanent sample plots. In line with this approach, FRTC continued field measurements and data analysis beyond the initial FRA cycle, thereby enabling periodic updating of forest inventory information at approximately five-year intervals. The second round of national forest inventory measurements was completed during 2016–2021.

This Second FRL assessment utilizes updated and expanded NFI data generated from the continued FRA implementation during 2016–2021. The dataset comprises remeasurements of 1,553 permanent forest plots established during the initial FRA (2010–2014), along with additional forest plots established during the second inventory cycle, resulting in a total of 2,237 forest sample plots used for biomass estimation. The use of remeasured permanent plots ensures temporal consistency, improves the reliability of biomass change estimates, and strengthens the representation of forest dynamics across Nepal's physiographic regions.

Field plot–level inventory data from this second round of FRA measurements form the primary basis for estimating forest biomass and associated emission factors in the second FRL. A concise overview of the adopted field sampling design, applied allometric equations and emission factors, and key inventory results relevant to biomass estimation is presented in the following subsections.

5.2.1. Field sampling design

A two-phase stratified systematic cluster sampling design was adopted. An integrated approach was adopted in the forest inventory through interpretation of satellite images at the first phase and measurement, i.e. field inventory at the second phase. Details on stratification and sampling (Figure 6) as well as field inventory are available in the field manual (FRTC, 2022) and respective FRA reports(DFRS, 2014, 2014, 2015; DFRS., 2015a, 2015b). Whilst a wide range of forest biophysical parameters were assessed, a target precision of ±10% at the 95% confidence level was set for stem volume estimates. A total of 2237 forest plots in 672 clusters (Table 7) were measured during the NFI (2016-2021). Details of the second phase sampling for each physiographic region can be found in the respective physiographic region reports.

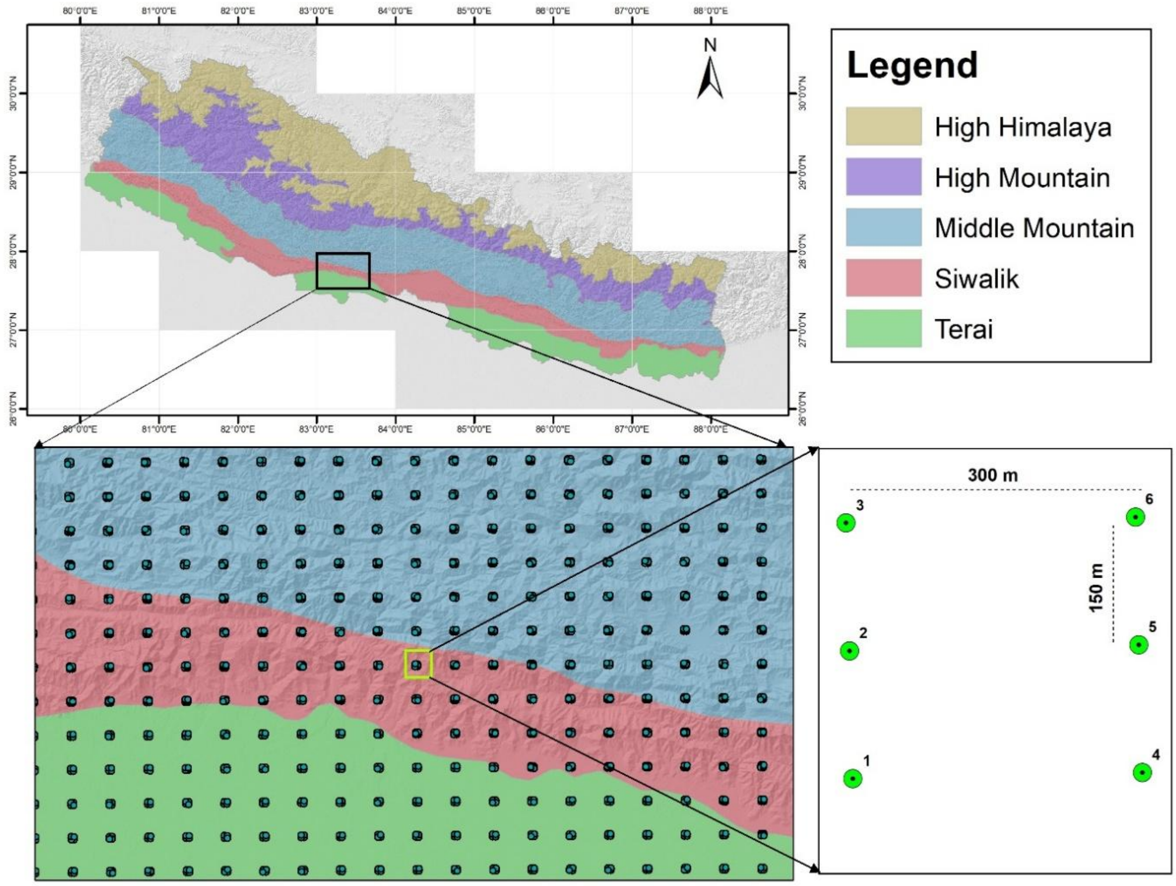


Figure 6: Stratification and sample plot design of NFI plots

In addition, summary of clusters and permanent sample plots is mentioned in Table 7.

Table 7: Distribution of clusters and permanent sample plots in 2015 and 2021

Physiographic region	Number of forest clusters		Number of sample plots				
			Forest plots			Non-forest plots	
	2015	2021	2015	2021	Additional plots (2016-2021)	Other wooded land	Other land
Terai	56	110	175	366	191	5	160
Churia	109	106	477	469	0	11	219
Middle Mountain	146	257	433	770	337	63	377
High Mountain & High Himal	139	199	468	632	164	26	130
Nepal	**450**	**672**	**1553**	**2237**	**692**	**105**	**886**

5.2.2. Stem volume estimation

Stem volume was estimated using Equation 1. Calculations and estimations were performed using the data analysis manual (FRTC, 2021).

Equation 1: Stem volume

$$\ln(V) = a + b\ln(d) + c\ln(h)$$

where,

ln = Natural logarithm to the base 2.71828

V = Volume (dm^3), computed as

$$V = \exp[a + b \times \ln(\text{DBH}) + c \times \ln(h)]$$

d is Diameter at Breast Height (DBH) in cm

h is total tree height in m

a, b, and c are species-specific coefficients.

Note: *Values were divided by 1,000 to convert them to m^3*

Species specific coefficients were used (Sharma & Pukkala, 1990) for calculating the volume of individual trees. The coefficients used for different species across different physiographic regions were reported in individual reports for physiographic regions.

5.2.3. Tree-stem biomass estimation

Biomasses of tree stems were estimated using Equation 2 and species-specific wood-density values (MPFS, 1989; Sharma & Pukkala, 1990). A carbon ratio factor of 0.47 (IPCC, 2006a, 2006b) was used for conversion into units of carbon stock.

Equation 2: Tree stem biomass

$$Stem\ biomass\ =\ V\ \ \times\ \rho$$

Where,

V = Stem volume calculated using Equation (1).

ρ = Air-dried wood density in kg/m^3

5.2.4. Tree-branch and foliage biomass estimation

The separate branch-to-stem and foliage-to-stem biomass ratio prescribed by MPFS (1989) were used to estimate branch and foliage biomasses from stem biomass. Dead trees were not taken into account for the estimation of branch and foliage biomass. The total biomasses of individual trees were estimated by using Equation 3.

Equation 3: Tree total biomass

$$Total\ Biomass\ =\ Stem\ biomass\ +\ Branch\ biomass\ +\ Foliage\ biomass$$

5.2.5. Organic carbon in litter and woody debris

Organic carbon in litter and woody debris fractions was obtained based on the total fresh mass collected from a known area as measured in the field. First, the dry mass of the litter and woody debris sub-sample was obtained by oven-drying it to a constant weight. Second, the total oven-dried weight of the litter and debris was estimated by multiplying the ratio of oven-dried to fresh weight of the litter and debris sub-samples. The total carbon content of litter and woody debris fractions was then obtained by summing the respective dry mass estimates per m^2, multiplied by 0.50, a carbon content constant suggested by (Pribyl, 2010).

5.2.6. Below-ground biomass estimation

This estimation was calculated by using the default value as recommended by *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019)*(*Chapter 4, Table 4.4), which provides updated, region-wise and forest-type-specific biomass allocation ratios. A root-to-shoot ratio coefficient of 0.44 was used, corresponding to the ratio of below-ground to above-ground biomass for natural forests of the sub-tropical dry ecological zone of Asia. The biomass of seedlings and saplings having DBH less than 10cm was not incorporated.

5.2.7. Above-ground Tree Biomass (air-dry and oven-dry)

The national average above-ground biomass in Nepal's forests was 205.28 *t/ha*. The forests of High Mountains and High Himal contained the highest above-ground biomass per hectare (258.29 *t/ha*), whilst the Middle Mountain contributed to the lowest (140.22 *t/ha*) (Table 8).

Table 8: Above-ground biomass (air-dry and oven-dry) component (t/ha)

Physiographic region	Stem	Branch	Foliage	Tree (air-dry)	Tree (oven-dry)	Litter and debris	Total (oven-dry)

Terai	158.82	57.29	9.35	225.46	204.96	0.60	205.56
Churia	131.6	46.06	8.06	185.72	168.84	0.60	169.44
Middle Mountain	98.27	45.17	10.15	153.59	139.62	0.60	140.22
High Mountain and High Himal	151.61	106.87	24.28	282.76	257.05	1.24	258.29
National average	**134.52**	**74.37**	**16.05**	**224.94**	**204.49**	**0.79**	**205.28**

Note: Forest litter and debris biomass had not been considered in the FRL calculations due to their insignificant contribution (<1%) in the total biomass

5.3. Reliability of Inventory Results

Each sample cluster in forest areas was allocated systematically in all physiographic regions and strata. Reliability of the inventory results in terms of stem volume per hectare was first determined for each stratum, on the basis of which reliability of results for national level was determined using defined methodology (Cochran, 1997). While designing this assessment, a 95% confidence limit was set for the inventory result with a range of 10% of the stem volume or biomass (DFRS., 2015b). The standard error for forest plots at national level was found to be 4.26 m^3/ha and error of mean was 4.87 % (Table 9). This result is within the reliability limits set out in the project document.

Table 9: Standard errors and confidence limits in Forest by physiographic regions

Physiographic region	No. of cluster	No. of plot	Mean stem volume (m³/ha)	Standard error of mean	Percentage of error of mean at 95% CL	95% Confidence limits of mean	
Terai	110	366	192.24	5.33	5.43	181.80	202.68
Churia	106	469	159.01	6.21	7.66	146.83	171.20
Middle Mountain	257	770	136.69	5.47	7.85	125.96	147.41
High Mountain & High Himal	199	632	225.78	11.27	9.79	203.69	247.88
National	**672**	**2237**	**186.73**	**4.26**	**4.47**	**178.38**	**195.08**

5.4. Estimation of Emission Factor for Forest Degradation

The emission factor for forest degradation was developed using an integrated approach of NFI permanent sample plots' data with high-resolution satellite imagery interpreted through OpenForis–Collect Earth Online. The methodological workflow is summarized in Figure 7 and elaborated in detail below.

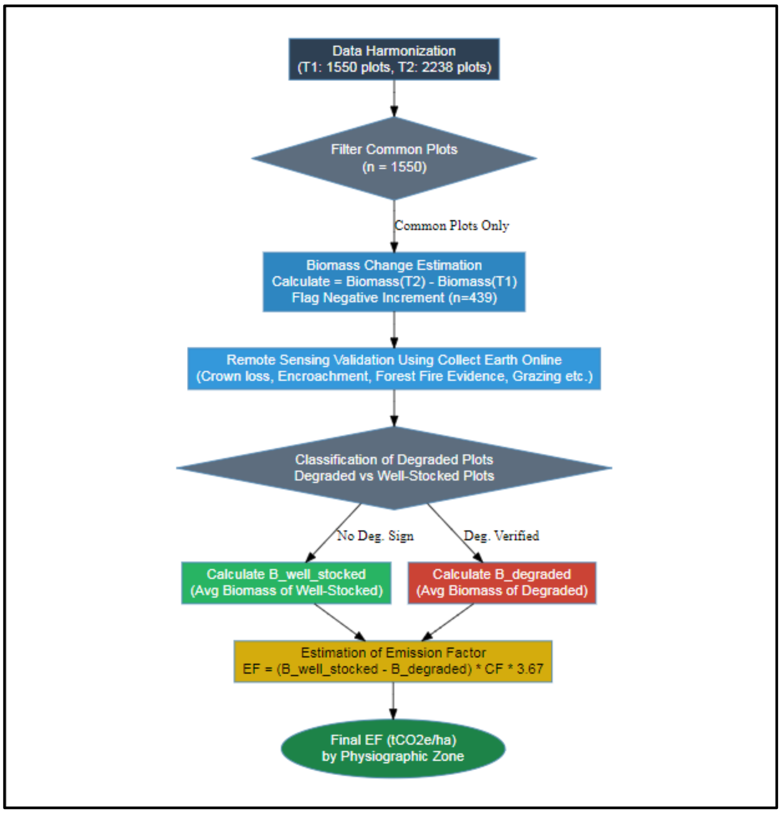


Figure 7: Methodological Flow Chart for Estimating Emission Factor of Degradation

5.4.1. Data Harmonization

Two temporal datasets of forest inventory plots were used: T1, corresponding to the initial FRA measurements (2010–2014), and T2, corresponding to the continued FRA/NFI measurements conducted during 2016–2021. The T1 dataset comprised 1,550 forest PSPs, while the T2 dataset included 2,238 forest PSPs, incorporating both remeasured plots and additional plots established during the second inventory cycle.

To ensure temporal consistency for change detection, plot identifiers, spatial coordinates, measurement protocols, and biomass estimation procedures were harmonized across the two datasets. Only plots that were common between T1 and T2 (n = 1,550) were retained for degradation analysis. Plots available only at T2 were excluded from change analysis and reserved as a baseline dataset for future monitoring cycles.

Table 10: Above-ground biomass (tDM/ha) in degraded and well stocked forest plots

Physiography	Degraded Forests			Well Stocked Forests			Δ Degradation	
	Plots	AGB	SD	Plots	AGB	SD	AGB	SD
Terai	24	58.59	39.70	147	237.95	110.34	179.36	117.27
Churia	31	83.00	82.78	435	176.41	90.68	93.41	122.78
Middle Mountain	62	98.38	118.19	361	153.10	135.23	54.72	179.60
High Mountain & High Himal	76	195.93	248.31	383	265.54	224.76	69.61	334.93

5.4.2. *Biomass Change Estimation*

For each common plot, above-ground biomass was estimated independently for T1 and T2 using the allometric equations and biomass expansion procedures. Plot-level biomass change (ΔB) was then calculated using Equation 4:

Equation 4: Plot-level biomass change

$$\Delta B = B_{T2} - B_{T1}$$

where,
ΔB = Change in plot-level biomass
BT2 = Biomass of year T2
BT1 = Biomass of year T1

A total of 439 plots, exhibiting negative biomass change ($\Delta B < 0$), were flagged as potential degradation plots and subjected to further screening. This step ensured that only plots with measurable biomass loss entered the degradation assessment pipeline.

5.4.3. *Remote Sensing Validation Using Collect Earth Online*

All flagged plots were visually interpreted in OpenForis–Collect Earth Online. This assessment focused on identifying visible indicators of forest degradation using multiple temporal images around the measurement dates.

5.4.4. *Classification of Degraded Plots*

Based on the combined evidence from field-measured biomass change and remote sensing interpretation, plots were classified as degraded forest plots only if both criteria were met. Plots failing the visual confirmation were excluded from degradation estimates to avoid overestimation. Following this screening, 193 plots were confirmed as degraded and retained for estimation of the emission factor.

5.4.5. *Estimation of Emission Factor*

The emission factors applied in this assessment are derived from biomass estimates obtained from permanent sample plots measured by the FRTC during the period 2016–2021. The emission factor for forest degradation was estimated using a difference-based approach, consistent with IPCC guidance (Equation 5). For each physiographic region, two reference biomass states were defined.

Equation 5: Emission factor for forest degradation

$$EF_{deg} = (B_{base} - B_{deg}) \times CF \times \frac{44}{12}$$

where,
EF_{deg} = emission factor for forest degradation
B_{base} = average above-ground biomass of well-stocked (non-degraded) forest plots at T1 (base) year
B_{deg} = average above-ground biomass of degraded forest plots at T2 year
CF = carbon fraction of dry biomass (0.47), and

44/12 is the molecular weight ratio for conversion of carbon to CO_2.

Finally, the degradation emission factors for each physiographic region were estimated separately. The resulting emission factors are expressed in $tCO_2e\ ha^{-1}$ and are used in conjunction with activity data to estimate emissions from forest degradation.

The national average emission due to forest degradation was 233.94 t CO_2/ha (Table 11). The emission was the highest in Terai physiographic region with 445.11 t CO_2/ha. The Churia, Middle Mountain, and High Mountain and High Himal regions had respectively 231.81, 135.78, and 172.75 t CO_2/ha.

Table 11: Emission factor from forest degradation (*Biomass (oven-dry) in ton per ha)*

Physiographic region	AGB	BGB	Total carbon	CO_2 equivalent
Terai	179.36	78.92	121.39	445.11
Churia	93.41	41.10	63.22	231.81
Middle Mountain	54.72	24.08	37.03	135.78
High Mountain and High Himal	69.61	30.63	47.11	172.75
National	**94.27**	**41.48**	**63.80**	**233.94**

5.5. Estimation of Emission Factor for Deforestation

The emission factor for deforestation was estimated using an integrated field- and remote sensing–based approach, consistent with the methodology previously applied for forest degradation and aligned with IPCC good practice guidance. The approach combines NFI permanent sample plot (PSP) data with high-resolution satellite imagery interpreted through OpenForis–Collect Earth Online (CEO) to ensure robust identification of forest loss and accurate estimation of associated biomass emissions (Figure 8).

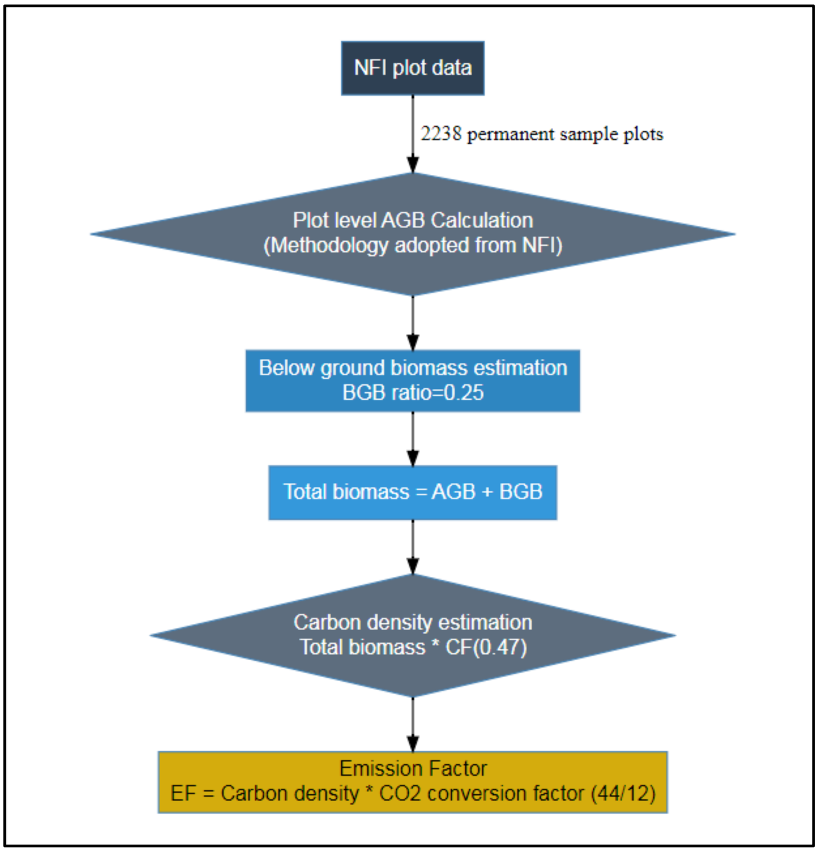


Figure 8: Methodological Flow Chart for Estimating Emission Factor of Degradation

5.5.1. Plot-level Biomass Calculation

National updated NFI data was used to calculate plot-level above-ground biomass. Biomass estimation followed the methods adopted in the national-level forest resource assessment. Below-ground biomass was estimated using a fixed coefficient of 0.44 of AGB, and total biomass was calculated as the sum of AGB and BGB.

5.5.2. Carbon Density Estimation

Total biomass was converted to carbon density using the IPCC default carbon fraction of 0.47.

5.5.3. Estimation of Emission Factor

The emission factors applied in this assessment are derived from biomass estimates obtained from permanent sample plots measured by the FRTC during the period 2016–2021. Emissions from deforestation were estimated by converting carbon stocks to CO_2 equivalents using IPCC-consistent conversion factors. The emission factor for deforestation was calculated following Equation (6):

Equation 6: Emission factor for deforestation

$$EF_{def} = C \times CF \times \frac{44}{12}$$

where,
EF_{def} = emission factor for deforestation
C = carbon density
CF = carbon fraction of dry biomass (0.47), and
$44/12$ is the molecular weight ratio for conversion of carbon to CO_2

Finally, emission factors were derived and expressed in and subsequently used in combination with activity data to estimate emissions from deforestation. The emission due to the deforestation was the highest in Terai physiographic region with 509.09 t CO_2/ha. The Churia, Middle Mountain, and High Mountain and High Himal regions had respectively 419.37, 346.81, and 638.48 t CO_2/ha. (Table 12)

Table 12: Emission factor from deforestation *Biomass (oven-dry) in ton per ha*

Physiographic region	AGB	BGB	Total carbon	Emissions per ha t CO_2e/ha
Terai	204.96	90.18	138.72	509.09
Churia	168.84	74.29	114.27	419.37
Middle Mountain	139.62	61.43	94.50	346.81
High Mountain and High Himal	257.05	113.10	173.97	638.48

5.6. Forest Enhancement

Detected afforestation in Nepal concerns mainly assisted natural regeneration which on average takes 20 years to grow back to the average biomass stock of forest in the five different physiographic regions. The annual growth is therefore obtained by dividing the average biomass in the physiographic regions (Table 13) by 20 (Poorter et al., 2021) and then multiplying by 3.5, which represents the average age of the afforested area during 2008-2017.

Table 13: The removal from afforestation across physiographic region

Physiographic region	AGB	BGB	Total carbon	Removals per ha t CO_2e/ha
Terai	35.87	15.78	24.28	89.09
Churia	29.55	13.00	20.00	73.39
Middle Mountain	24.43	10.75	16.54	60.69
High Mountain and High Himal	44.98	19.79	30.45	111.73

6. RESULTS ON EMISSION AND REMOVAL

6.1. Forest Cover Change between 2008-2017

Forest cover change between during the 13 years historical period (2008-2017) was obtained using the LandTrendr algorithm in GEE. Landsat timeseries images between 2008 and 2017 were used along with land cover maps of year 2008 and 2017 to derive the five strata of change classes namely: stable forest, forest degradation, deforestation, stable non forest and forest gain/enhancement. Figure 9 shows the map of the forest cover change map. The map information was further used to derive the bias-corrected area estimates of each change class.

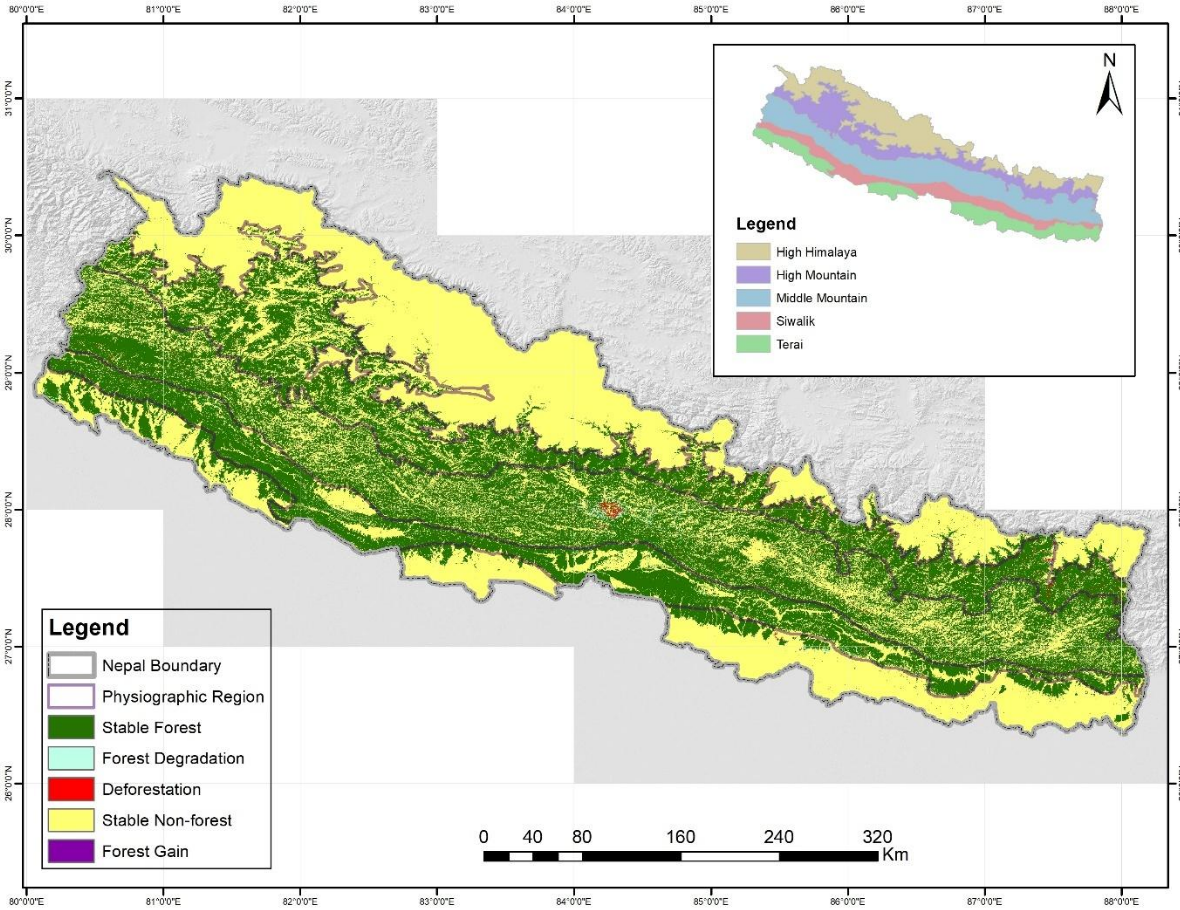


Figure 9: Map of Landcover Change under REDD+ Activity

6.2. Deforestation

Deforestation varied considerably across Nepal's physiographic regions. The High Mountain and High Himal region showed the largest estimated deforestation area of 10,363 ha. In contrast, the Terai and Churia regions exhibited comparatively lower deforestation estimates of 1,055 ha and 1,876 ha, respectively. The national average of **22,385** ha deforestation area suggested a substantial overall deforestation area, though the relatively large standard error highlighted considerable variability across regions (Table 14).

Table 14: Physiographic region-wise deforestation area (Ha)

Physiographic Region	Deforestation Area	Standard Error	Confidence Interval (±)
Terai	1055	89	174
Churia	1876	264	517
Middle Mountain	4745	577	1131
High Mountain and High Himal	10363	334	655
National Average	**22385**	**937**	**1836**

6.3. Forest Degradation

Forest degradation was higher than deforestation across all physiographic regions. The highest area (219,684 ha) had been recorded in the Middle Mountain regions, followed by the High Mountain and High Himal region, Churia region, and Terai region by 160,273 ha, 39,350 ha, and 42,876 ha, respectively. At the national level, the high degradation estimate (485,612 ha) emphasized the severity of forest degradation in Nepal, while the wide confidence interval reflected strong spatial variability and uncertainty across regions (Table 15).

Table 15: Physiographic region-wise forest degradation area (Ha)

Physiographic Region	Degradation Area	Standard Error	Confidence Interval (±)
Terai	42876	20576	40330
Churia	39350	22169	43451
Middle Mountain	219684	73729	144509
High Mountain and High Himal	160273	46052	90262
National Average	**485612**	**80898**	**158561**

6.4. Enhancement of forest carbon stocks

The higher forest enhancement (afforestation and reforestation) activities in the Middle Mountain region (108550 ha), and Churia region (45830 ha), indicated comparatively significant restoration efforts in these regions. On the other hand, the Terai and the High Mountain and High Himal regions showed comparatively lower areas of forest enhancement of 20585 ha and 18447 ha, respectively (Table 15).

Table 16: Physiographic region wise forest enhancement (afforestation/reforestation) area (Ha)

Physiographic Region	Afforestation/ Reforestation Area	Standard Error	Confidence Interval (±)
Terai	20585	19007	37254
Churia	45830	25631	50237
Middle Mountain	108550	40972	80305
High Mountain and High Himal	18447	16762	32854
National Average	**193758**	**54288**	**106404**

Figure 10 highlights the overall activity data estimates across all physiographical regions along with their confidence intervals.

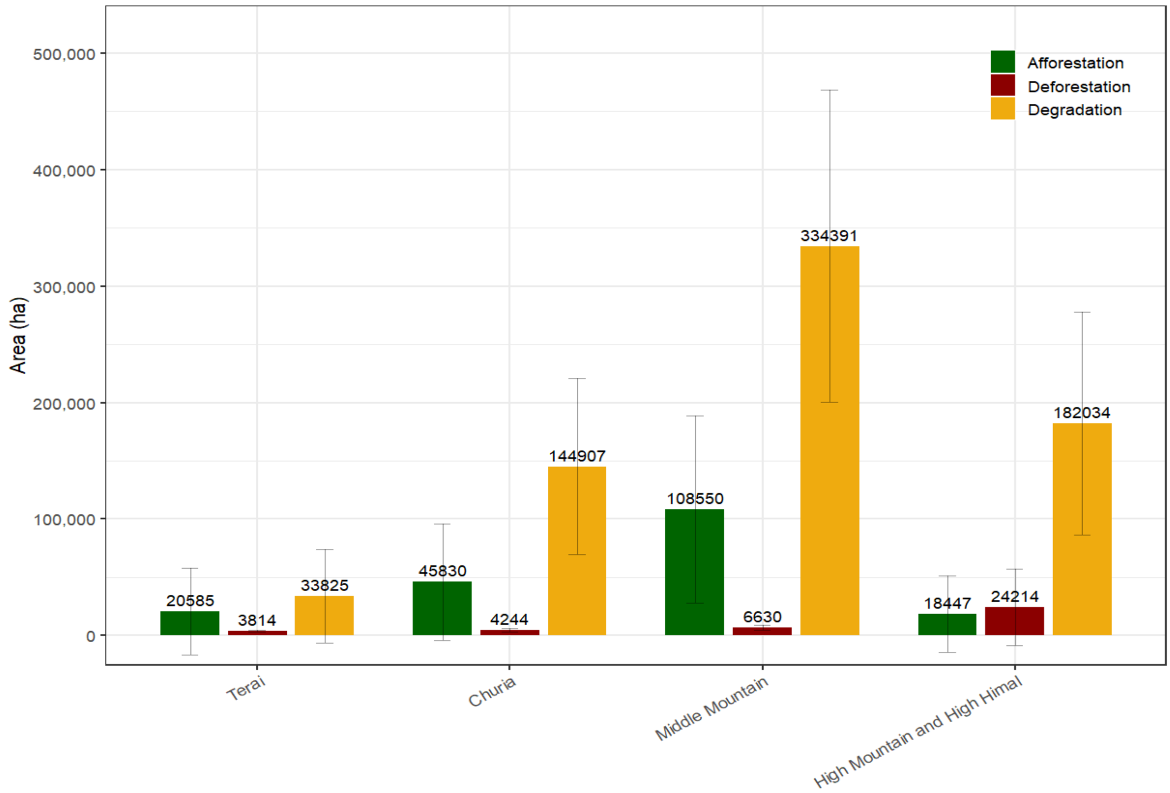


Figure 10: Summary Graph of Activity Area Estimates with Confidence Intervals

6.5. Forest Degradation, Deforestation, and Afforestation - Carbon Fluxes

6.5.1. Emission from deforestation across the physiographic regions

Emission distribution from deforestation across different physiographic regions is presented in Table 17. Among the physiographic regions, the High Mountain and High Himal region contributes the largest share of emissions, with an annual emission of 0.66 million t CO_2. This is primarily attributed to the extensive area affected by deforestation (10,363 ha) combined with a relatively high emission factor. The Middle Mountain, Terai, and Churia regions contribute comparatively smaller but still significant shares, reflecting differences in deforested area and emission factors across regions.

Table 17: Annual emission from deforestation by Physiographic Regions

Physiographic region	Area (ha)	Emission factor (t CO_2/ha)	Emission (t CO_2)	Annual Emission (t CO_2)
Terai	1055	509.09	537090	53709
Churia	1876	419.37	786738	78674
Middle Mountain	4745	346.81	1645613	164561

High Mountain and High Himal	10363	638.48	6616568	661657

6.5.2. *Emission from forest degradation across the physiographic regions*

Emission from forest degradation across different physiographic regions is presented in Table 18. The Middle Mountain region contributes the largest share of emissions, with an annual emission of 2.98 million t CO_2, primarily due to the extensive area affected by forest degradation (219,684 ha). Substantial emissions are also observed in the Churia and High Mountain and High Himal regions, reflecting the large extent of degraded forest areas, while the Terai region contributes a comparatively smaller share.

Table 18: Annual emission from forest degradation by Physiographic Regions

Physiographic region	Area (ha)	Emission factor (t CO_2/ha)	Emission (t CO_2)	Annual Emission (t CO_2)
Terai	42876	445.11	19084536	1908454
Churia	39350	231.81	9121724	912172
Middle Mountain	219684	135.78	29828694	2982869
High Mountain and High Himal	160273	172.75	27687161	2768716

6.5.3. *Removal from Forest Enhancement across the physiographic regions*

Carbon removals from afforestation across different physiographic regions are presented in Table 19. The Middle Mountain region contributes the largest share of removals, with an annual removal of approximately 1.93 million t CO_2, primarily due to the extensive area of forest gain (229,568 ha). The Churia and High Mountain and High Himal regions also contribute substantially to total removals, while the Terai region accounts for a comparatively smaller share.

Table 19: Annual removal from forest enhancement by Physiographic Regions

Physiographic region	Area (ha)	Removal factor (t CO_2/ha)	Removal (t CO_2)	Annual Removal (t CO_{2e})
Terai	20585	145.09	2986678	229744
Churia	45830	119.52	5477602	421354
Middle Mountain	108550	98.84	10729082	825314
High Mountain and High Himal	18447	181.75	3352742	257903

6.5.4. *Annual Emissions and Removals – National Level*

Table 20 summarizes annual emissions and removals from deforestation, forest degradation, and afforestation/reforestation across different physiographic regions. At the national level, annual emissions from deforestation amount to 0.96 million tCO_2e, while emissions from forest degradation are substantially higher at 8.5 million tCO_2e per year. In contrast, annual removals from afforestation and reforestation are estimated at 2.5 million tCO_2e. Among the physiographic regions, the High Mountain and High Himal region contribute the largest share of emissions from deforestation, whereas the Middle Mountain region is the dominant source of emissions from forest degradation. The Middle Mountain region also accounts for the highest annual removals from afforestation and reforestation, reflecting the extensive area of forest gain in this region.

Table 20: Annual emissions and removals from deforestation, forest degradation, and afforestation

Physiographic region	Annual emissions from deforestation (tCO_2e)	Annual emissions from forest degradation (tCO_2e)	Annual removals from afforestation/reforestation (tCO_2e)
Terai	53709	1908454	250993
Churia	78674	912172	322894
Middle Mountain	164561	2982869	1393248
High Mountain and High Himal	661657	2768716	568728
Nepal	**958601**	**8572211**	**2535863**

7. Uncertainty Assessment

7.1. Background

Uncertainties in global forest carbon flux estimates hinder the effectiveness of REDD+ and the Paris Agreement Global Stocktake, requiring more frequent national forest inventories and carbon mapping (Butler et al., 2024). REDD+ reporting specialists are keen to get better estimates of uncertainty in forest carbon accounting (Grainger & Kim, 2020). Estimating greenhouse gas emissions for REDD+ programs is inherently complex, as it relies on a combination of land-use change data and forest inventory measurements. While these datasets provide a necessary foundation for calculating carbon fluxes, they are subject to various forms of error, ranging from measurement inaccuracies in the field to classification errors in satellite imagery. An explicit uncertainty assessment allows us to understand the confidence we can place in our emission estimates sensitivity of the variables used for overall estimation of emission. Conventional uncertainty analysis often fails to estimate how each input affects the final result. The Monte Carlo method offers several benefits compared with traditional approaches for estimating uncertainty, particularly for outputs from complex measurement systems (Papadopoulos & Yeung, 2001) and it has been an important method for exploring problems that are difficult or impossible to solve analytically (Harrison et al., 2010).

This chapter describes how Monte Carlo simulation was used to estimate uncertainty under given/calculated measure of central tendency (mean) and measure of dispersion (relative standard error) over 10000 simulations.

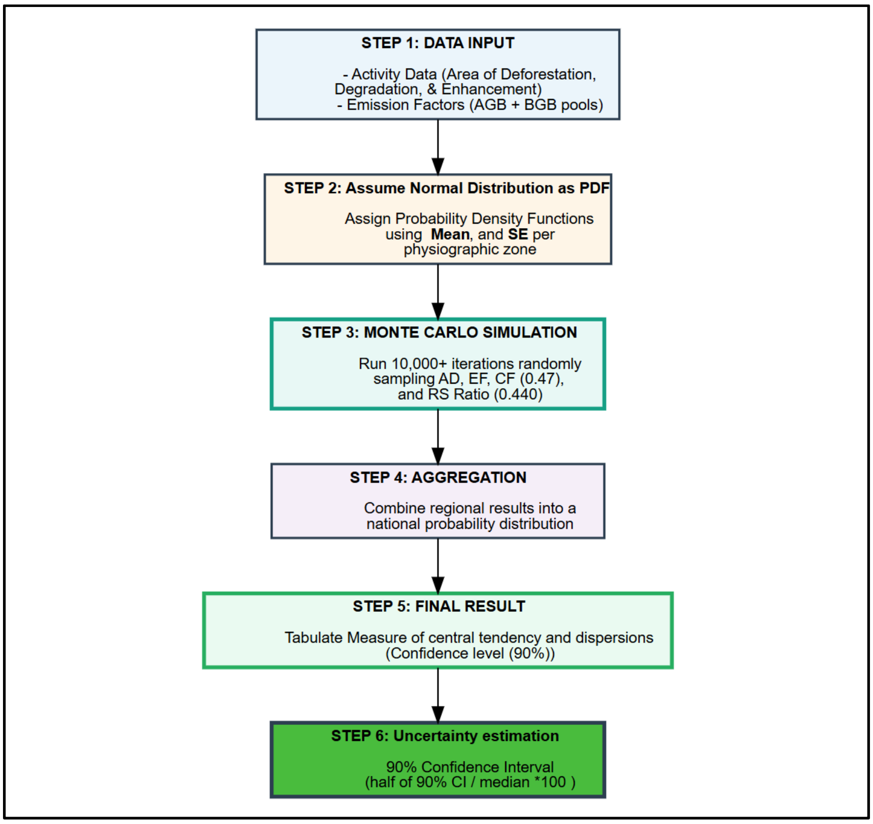


Figure 11: Workflow of uncertainty analysis

7.2. Sources of Uncertainty

The uncertainty in our emission calculations stems from three primary components: Activity Data, Emission Factors, and the constant parameters used for carbon conversion. The methods for calculating the activity data and above-ground biomass are presented in Chapters 4 and 5. The summary of activity data and its parameters used for uncertainty assessment are as follows:

7.2.1. Activity Data

The primary source of uncertainty lies in mapping deforestation, degradation, and forest enhancement across Nepal's diverse physiographic regions. These figures were derived from satellite imagery (2008–2017), where errors often arise from the difficulty of distinguishing between subtle forest cover changes and natural seasonal variations, particularly in the rugged High Mountain and High Himal regions.

7.2.2. Emission Factors

Emission factors were calculated based on above-ground biomass calculated using the defined methodology of national FRA where allometric equations were used to estimate tree-level volume and biomass, along with branch and foliage biomasses. The aboveground biomass in Nepal is highly varied due to the effect of allometric equation, wood density and species composition, especially in the higher region (Khanal et al., 2024). The study considers the uncertainties from the plot-level variation of above-ground biomass under different activities. As shown in Table 21, the standard error of the mean for above-ground biomass varies by region, with the High Mountain and High Himal regions showing higher variability compared to the Lower regions.

Table 21: Sample statistics used for uncertainty estimation for deforestation

Physiographic Region	Number of Plots	AGB	SD	SE
Terai	366	204.96	121.09	6.32
Churia	469	168.84	93.91	4.34
Middle Mountain	770	139.62	123.22	4.44
High Mountain & High Himal	632	257.05	223.78	8.90

Similarly, the variability of biomass loss from degradation as well as the biomass growth from afforested areas are noticed higher in the Middle Mountain and High Mountain and High Himal regions as well (Table 22 and Table 23).

Table 22: Sample statistics used for uncertainty estimation for degradation

Physiographic Region	Number of Plots	AGB	SD	SE
Terai	24	179.36	110.52	22.56
Churia	31	93.41	91.13	16.37
Middle Mountain	62	54.72	135.67	17.23
High Mountain & High Himal	76	69.61	225.31	25.85

The higher variability of statistics seen in higher regions impacted the uncertainty of the respective regions.

Table 23: Sample statistics used for uncertainty estimation for Forest Enhancement

Physiographic Region	Number of Plots	AGB	SD	SE
Terai	366	58.41	32.47	1.69
Churia	469	48.12	26.77	1.24
Middle Mountain	770	39.79	35.12	1.27
High Mountain & High Himal	632	73.26	63.78	2.54

7.2.3. Carbon Parameters:

To calculate total carbon, we applied a Carbon Fraction (CF) of 0.47 and a Root-to-Shoot (RS) ratio of 0.440 to account for below-ground biomass. These are often default values or averages across forest types rather than site-specific measurements. They introduce a level of "model uncertainty" into the final calculation of total tCO_2 per ha. The ratio and carbon fraction with their uncertainties (Table 24) were taken from IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a).

Table 24: Parameters used for uncertainty estimation

	Mean	SE
R:S	0.44	0.184
CF	0.47	0.014

The uncertainties of annual emissions/removals of deforestation, forest degradation and forest enhancement, resulting from the Monte Carlo simulation (n=10000 iterations), are presented in Tables 25 – 27, respectively.

Table 25: Results of uncertainty estimation on emission from deforestation

Physiographic Region	Mean	Half of 90 % CI	Uncertainty (%)
Terai	41244	10712	26.13%
Churia	60452	19357	32.27%
Middle Mountain	126627	37735	30.05%
High Mountain and High Himal	508791	116332	22.94%
Nepal	737113	165521	22.51%

Table 26: Results of uncertainty estimation on emission from forest degradation

Physiographic Region	Mean	Half of 90 % CI	Uncertainty (%)
Terai	1474676	1251421	87.92%
Churia	700233	693181	104.49%
Middle Mountain	2292758	1827144	85.25%
High Mountain and High Himal	2136691	1738447	87.02%

Nepal	6604358	3170484	49.19%

Table 27: Results of uncertainty estimation on removals from forest enhancement

Physiographic Region	Mean	Half of 90 % CI	Uncertainty (%)
Terai	195322	219883	115.06%
Churia	248747	230182	93.68%
Middle Mountain	1072520	664458	63.35%
High Mountain and High Himal	440171	417766	96.85%
Nepal	1956760	906519	46.98%

8. PROPOSED FOREST REFERENCE LEVEL

8.1. Result of the FRL estimation

Nepal's FRL is hereby submitted to account for GHG emissions due to deforestation and forest degradation, and of GHG removals due to the enhancement of forest carbon stock (afforestation/reforestation) between 2008 and 2017. The definition and context of using these activities are detailed in sub section 3.3. Brief details on emissions and removals from each activity and on the FRL at the national level, based on these three activities, are given below. The corresponding values for each activity and the final FRL are presented in Figure 12.

8.2. Emissions from Deforestation

The activity data of deforestation areas is derived at physiographic region level using bias-corrected forest cover change area estimates prepared using Landsat TM, Landsat ETM and Landsat 8 satellite data of 2008-2017, land cover maps of 2008 and 2017 using LandTrendr algorithm in Google Earth Engine. The bias correction factors were used for deforestation based on the accuracy assessment of the forest cover change assessment. At national level, the bias-corrected deforestation area is estimated at 22,385 ha during the historical reference period of 2008-2017 which corresponds to annual deforestation of 2,238 ha/year and physiographic region wise calculations are used for emission estimation.

The details on estimates for physiographic regions, along with tables on activity data and emission factors, are given in Sections 5 and 6. At the national level, the CO_2 emission due to deforestation is estimated at 958,601 tCO_2e/year.

8.3. Emissions from Forest Degradation

Similar to the deforestation and forest enhancement (afforestation/reforestation) the activity data of forest degradation is derived at the physiographic region level using bias-corrected forest cover change area estimates prepared using Landsat TM, Landsat ETM and Landsat 8 satellite data of 2008-2017, land cover maps of 2008 and 2017 using LandTrendr algorithm in Google Earth Engine. The bias correction factor used for forest degradation was based on the accuracy assessment of the forest cover change assessment. At the national level, the bias-corrected forest degradation area is estimated to be 485,612 ha during the historical period of 2008-2017, corresponding to 48,561 ha/year. Physiographic regions are used for emission and removal estimation.

The details on estimates for physiographic regions, along with tables on activity data and emission factors, are given in Sections 5 and 6. At the national level, the CO_2 emissions resulting from forest degradation are estimated to be 8,572,211 tCO_2/year.

8.4. Removals from Enhancement of forest carbon stock (Reforestation/ Afforestation)

The activity data for the enhancement of carbon stock (reforestation and afforestation areas) is derived at the physiographic region level using bias-corrected forest cover change area estimates prepared using Landsat TM, Landsat ETM and Landsat 8 satellite data of 2008-2017, land cover maps of 2008 and 2017 using LandTrendr algorithm in Google Earth Engine. The bias correction factors were used for enhancement of forest carbon stocks based on the accuracy assessment of the forest cover change assessment. At national level, the bias-corrected reforestation or afforestation areas are estimated at 3,02,833 ha during the historical period of 2008-2017, which corresponds to annual afforestation/reforestation of 30,283 ha/year and physiographic region wise calculations are used for emission and removal estimation.

The details on estimates for physiographic regions, along with tables on activity data and emission/removals factors, are given in Sections 5 and 6. At the national level, the CO_2 removals due to the enhancement of forest carbon stocks (reforestation/afforestation) are estimated at 25,35,863 t CO_2/year.

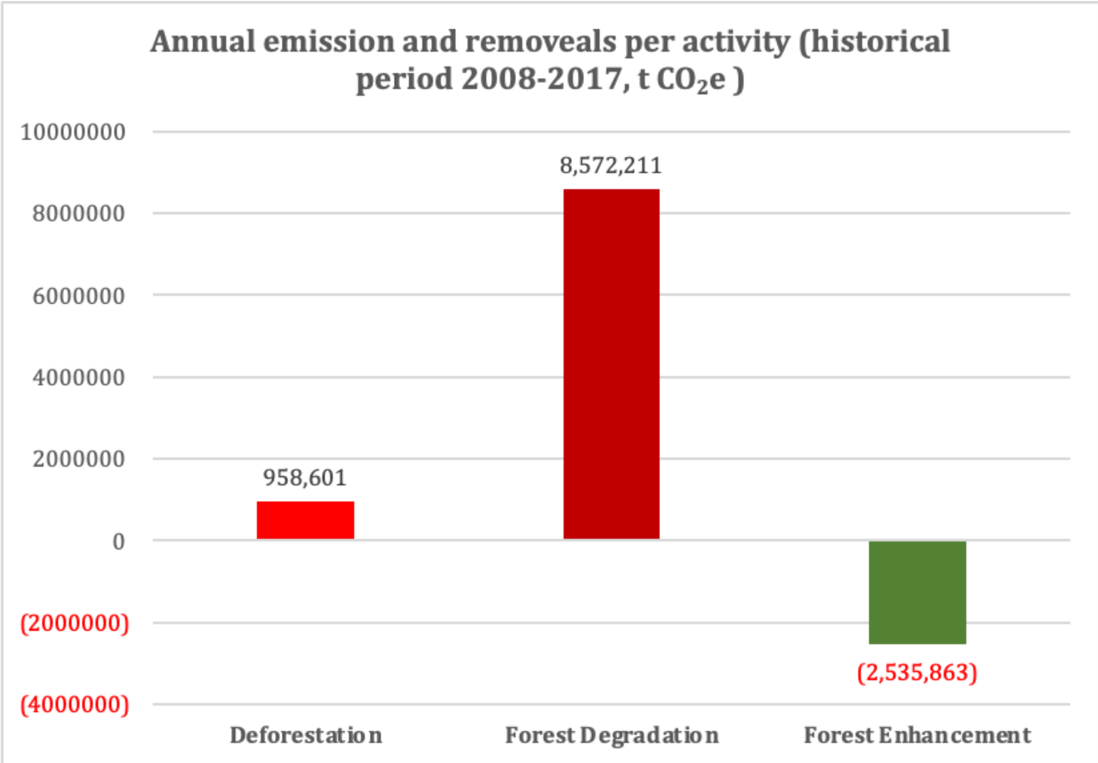


Figure 12: Annual CO_2 emissions/removals per REDD+ activity of Nepal (t CO_2e/yr)

9. FUTURE IMPROVEMENTS

Nepal has identified the following specific areas for improvement of the FRL on which the country seeks to continue research, data collection and testing of methodologies, dependent on available resources. These are the following:

- Fully include the activity on sustainable forest management and conservation of carbon stock on forest land remaining forest land. This would allow Nepal to report on the important results of improved forest management achieved in the country through the community forestry programme,
- Improve the accuracy of the emission/removal estimates of the regions/activities which have large uncertainty associated with the data,
- Improve the deforestation and forest enhancement emission/removals by incorporating change class (according to final/initial land use class) wise data and information,
- Include small-scale deforestation and afforestation in a cost-efficient manner with sufficient accuracy,
- Include non-CO_2 emission from forest fire,
- Research and data production on the emission factors of degradation from individual drivers

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11. ANNEXES

ANNEX 1: Collection of reference data for forest cover change accuracy assessment and unbiased area estimates using OpenForis-Collect Earth Online

Accuracy Assessment (Response Design)

Agreement of map data and reference data is determined using *OpenForis-Collect Earth Online* developed by SERVIR. Google Earth high resolution imagery tiles are taken as reference data source and sample data collection was done using *OpenForis-Collect Earth Online*, a tool with html-based data entry platform that runs on top of Google Earth used to collect sample-based reference data. To further verify the change between 2008 to 2017, Landsat 5, 7, 8, and NDVI and NDFI images were also assessed. Figure A1 presents the Response Design flow chart used to identify land-use / land cover change designed in *OpenForis-Collect Earth Online*.

Sample plots earlier defined as the sampling design were uploaded into OpenForis-Collect Earth Online and considering the minimum mapping unit of change as 0.5 hectare, following labeling protocol were defined for reference data in OpenForis-Collect Earth Online:

Sampling plot size*: 70m X 70m (~0.5 hectare)*

Number of sample plots: *3600*

Number of sample points within plot: *9*

Distance between sample points within a plot: 23m

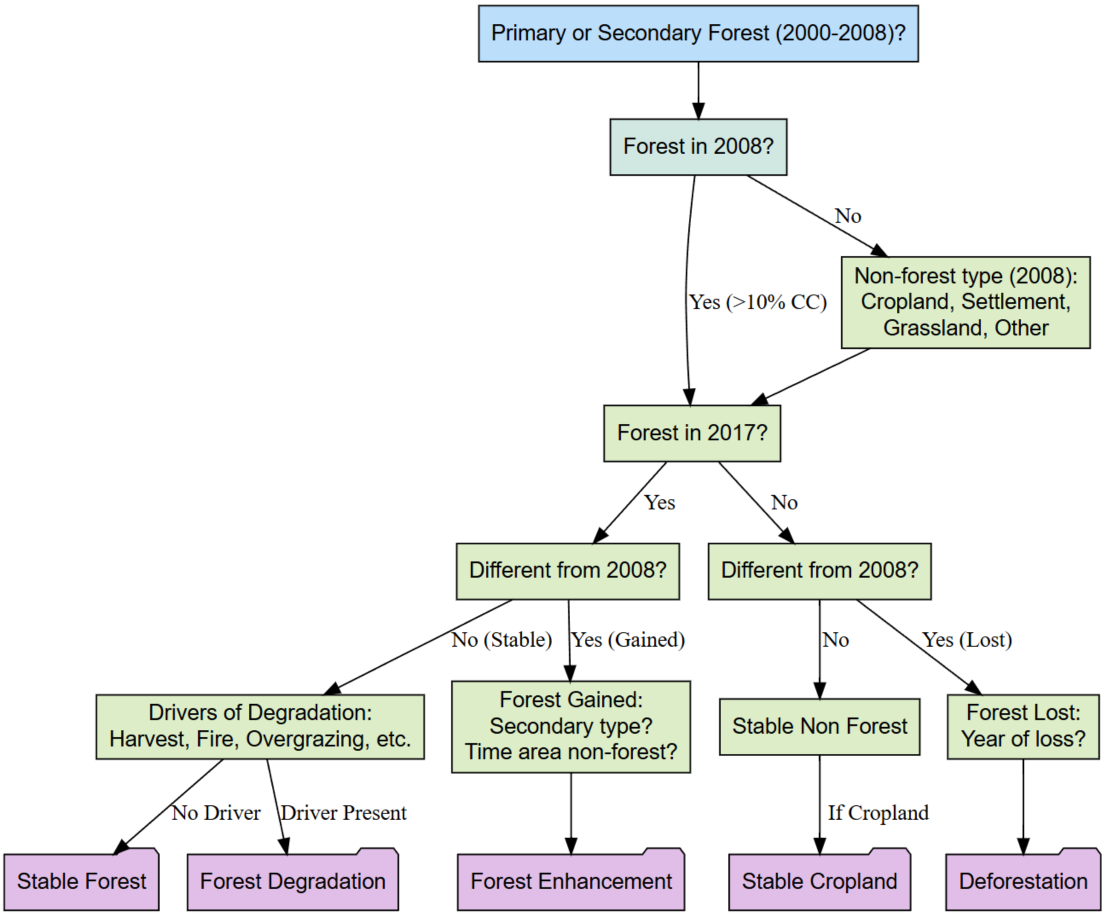

Figure A1: Flow chart of OpenForis-Collect Earth Online response design to assess deforestation, forest degradation and forest gain (enhancement of forest carbon stocks)

Minimum mapping unit was 0.5 hectare. Agreement definition mainly refers to the decision on reference class in case of a mixed land-use / land cover situation following the hierarchy threshold criterion from IPCC good practices guidelines.

Location of sample plots, change area (Forest loss and gain polygons) and other supporting documents are available to download at Collect Earth Online https://app.collect.earth/.

All 3600 plots were visually interpreted for identifying the changes (if any) in land-use / land cover. Following figures show the examples from the response design and data collection using collect earth online.

Reference data collection was conducted using OpenForis–Collect Earth Online.

Sample plot No. 3237, located at 28°36′45.04″ N, 81°12′13.19″ E, indicates forest loss, which was verified through visual interpretation in Google Earth using the Collect Earth Online platform.

Imagery Date:1/29/2011 ***Imagery Date: 01/12/2017***

Figure A2: Forest loss between 2011 and 2017 due to conversion to road construction

Sample plot no 1164, located at 27°21'00.14"N, 84°45'53.04"E, indicates* forest gain, which was *verified through visual interpretation in Google Earth using the Collect Earth Online platform.

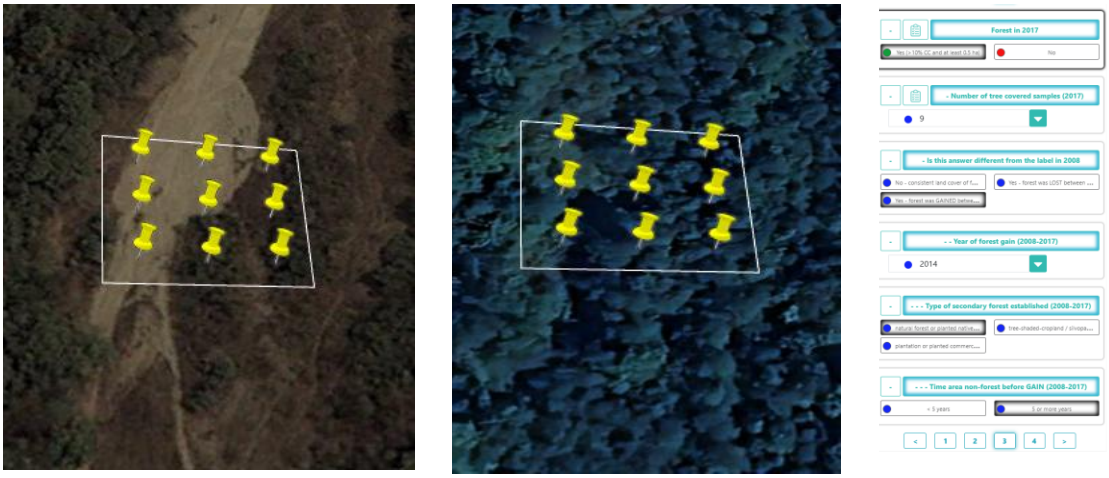

Image Date: 05/06/2008 Image Date: 11/03/2017

Figure A3: Forest gain due to restoration of other land to forest between 2008 and 2017

Sample plot no 3335, located at 27°47'03.94"N, 83°16'18.64"E, indicated* forest degradation, which was *verified through visual interpretation in Google Earth using the Collect Earth Online platform.

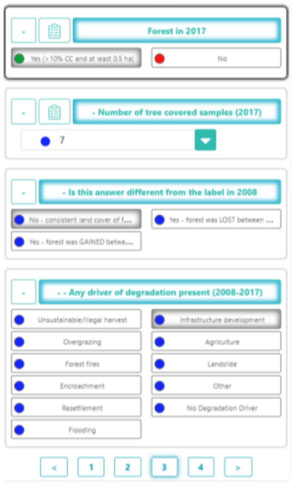

Image Date: 12/05/2009 Image Date: 04/09/2017

Figure A4: Forest degradation between 2009 and 2017

Annex 2: Error Matrix of map data and reference data (National)

Error Matrix ,Sample Counts									
	(Sample Points Comparison Table)								
Reference Class									
Mapped Class		Stable Forest	Degradation	Deforestation	Stable Non Forest	Gain	Total	Pixel	W_i
	Stable Forest	360	20	0	56	14	450	85787117	0.457691
	Degradation	351	237	15	226	21	850	1891929	0.010094
	Deforestation	202	157	189	242	10	800	911069	0.004861
	Stable Non Forest	24	3	0	470	3	500	98753874	0.526872
	Gain	228	18	1	253	500	1000	90457	0.000483
	Total	1165	435	205	1247	548	3600	187434446	1

Annex 3: Error Matrix of map data and reference data (Terai)

Error Matrix,Sample Counts									
	(Sample Points Comparison Table)								
Reference Class									
Mapped Class		Stable Forest	Degradation	Deforestation	Stable Non Forest	Gain	Total	Pixel	W_i
	Stable Forest	89	5	0	4	2	100	5087456	0.200516
	Degradation	86	49	5	54	6	200	88892	0.003504
	Deforestation	7	3	51	38	1	100	18621	0.000734
	Stable Non-Forest	1	1	0	98	1	101	20160834	0.794614
	Gain	59	1	0	30	110	200	16043	0.000632
	Total	242	59	56	224	120	701	25371846	1

Annex 4: Error Matrix of map data and reference data (Churia)

Error Matrix ,Sample Counts									
	(Sample Points Comparison Table)								
Reference Class									
Mapped Class		Stable Forest	Degradation	Deforestation	Stable Non Forest	Gain	Total	Pixel	W_i
	Stable Forest	92	2	0	4	2	100	17496942	0.732024
	Degradation	88	64	6	34	8	200	242110	0.010129
	Deforestation	21	22	31	24	2	100	43621	0.001825
	Stable Non Forest	10	0	0	87	2	99	6108713	0.255572
	Gain	16	4	1	87	92	200	10766	0.00045
	Total	227	92	38	236	106	699	23902152	1

Annex 5: Error Matrix of map data and reference data (Middle Mountain)

Error Matrix ,Sample Counts									
	(Sample Points Comparison Table)								
Reference Class									
Mapped Class		Stable Forest	Degradation	Deforestation	Stable Non Forest	Gain	Total	Pixel	W_i
	Stable Forest	57	5	0	30	7	99	35243705	0.64802
	Degradation	77	48	2	67	6	200	908741	0.016709
	Deforestation	90	63	32	108	7	300	409112	0.007522
	Stable Non Forest	6	2	0	92	0	100	17774248	0.326812
	Gain	98	10	0	91	151	350	50909	0.000936
	Total	**155**	**43**	**11**	**72**	**38**	1049	54386715	1

Annex 6: Error Matrix of map data and reference data (High Mountain and High Himal)

Error Matrix ,Sample Counts										
	(Sample Points Comparison Table)									
Reference Class										
Mapped Class		Stable Forest	Degradation	Deforestation	Stable Non Forest	Gain	Total	Pixel	W_i	
	Stable Forest	122	8	0	18	3	151	27958755	0.333744	
	Degradation	100	76	2	71	1	250	652183	0.007785	
	Deforestation	84	69	75	72		300	439714	0.005249	
	Stable Non Forest	7	0	0	193		200	54709765	0.65307	
	Gain	55	3	0	45	147	250	12741	0.000152	
	Total	368	156	77	399	151	1151	83773158	1	