Hariyo Ban Program

Forest Carbon Assessment in Chitwan-Annapurna Landscape

Forest Carbon Assessment in Chitwan-Annapurna Landscape

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Hariyo Ban Program

Forest Carbon Assessment in Chitwan-Annapurna Landscape

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Study Team
Bhishma P. Subedi,
Team Leader

Abbreviations and Acronyms

ANSAB	Asia Network for Sustainable Agriculture and Bioresources
ASTER	Advanced Space borne Thermal Emission and reflection Radiometer
CFUG	Community Forest User Group
CHAL	Chitwan-Annapurna Landscape
COP	Conference of Parties
DB	Dense Broad-leaf
DBH	Diameter at Breast Height
DN	Dense Needle-leaf
FCFP	Forest Carbon Partnership Facility
FECOFUN	Federation of Community Forestry Users, Nepal
FSC	Forest Stewardship Council
GDEM	Global Digital Elevation Model
GEOBIA	Geographic Object Based Image Analysis
GIS	Geographical Information System
GoN	Government of Nepal
GPS	Global Positioning System
GS	Gramm Schmidt
HCS	Hyper-spherical Color Sharpening
HH	Household
HIS	Hue Intensity Saturation
ICIMOD	International Centre for Integrated Mountain Development
INGO	International Non-governmental Organization
IPCC	Intergovernmental Panel On Climate Change
LRP	Local Resource Persons
LWM	Land Water Mask
MoFSC	Ministry of Forest and Soil Conservation
MRV	Measurement, Reporting and Verification
MSS	Multispectral Scanner
NARC	National Agriculture Research Council
NDSII	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NEFIN	Nepal Federation of Indigenous Nationalities
NGIIP	National Geographic Information Infrastructure Project
NGO	Non-governmental Organization
NIR	Near Infrared Radiation
NORAD	Norwegian Agency for Development Cooperation

NTFP	Non-Timber Forest Product
NTNC	National Trust for Nature Conservation
PCA	Principal Components Analysis
RECOFTC	The Center for People and Forests
REDD	Reducing Emissions from Deforestation and Forest Degradation
RPP	Readiness Plan Proposal
SAVI	Soil-Adjusted Vegetation Index
SB	Sparse Broad-leaf
SBSTA	Scientific and Technological Advice
SHL	Sacred Himalayan Landscape
SN	Sparse Needle-leaf
TAL	Terai Arc Landscape
TM	Thematic Mapper
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNIQUE	UNIQUE Forestry and Land Use GmbH, Germany
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
VDC	Village Development Committee
VSC	Verified Standard Carbon
WECS	Water and Energy Commission Secretariat
WGS	World Geodetic System
WV-2	World View 2

Executive Summary

This study, 'Forest Carbon Assessment in Chitwan-Annapurna Landscape (CHAL) for REDD+ Readiness Activities' presents the comprehensive baseline of forest carbon stock in CHAL with a detailed assessment of carbon sequestration potential, carbon-capture, permanency, leakage, and risks from the forest coverage.

Asia Network for Sustainable Agriculture and Bioresources (ANSAB) carried out the study in collaboration with the International Centre for Integrated Mountain Development (ICIMOD), and UNIQUE Forestry and Land Use GmbH in 2013-2014. The purpose was to generate a technical baseline and other socio-economic information necessary to initiate REDD+[1] readiness activities in CHAL for the conservation of biodiversity and increased benefits to the communities.

CHAL covers 32,090 sq. km. in 19 districts in the Kali, Seti, Marsyandi, and Trishuli river basins. This study covers 12 districts: Baglung, Dhading, Gorkha, Gulmi, Kaski, Lamjung, Manang, Mustang, Myagdi, Parbat, Syangja, and Tanahu. WWF Nepal studied the other seven districts in a detailed forest carbon assessment done for the Terai Arc Landscape (TAL) and Sacred Himalayan Landscape (SHL) initiatives.

Methodology: The study has three main components -- a rapid baseline survey of socio-economic conditions, geospatial analysis, and forest carbon assessment. The rapid baseline survey to analyze socio-economic conditions employed focus group discussions, key informant interviews, consultations with experts and stakeholders, and a literature review. The geospatial analysis used land/forest cover mapping, change detection, simulations, stratification, and verification. It used satellite data, GIS data, and relevant GIS software to identify and distinguish the project area, to recognize the forest areas, and to classify them into different strata in CHAL.

First, the study team conducted a pilot inventory to estimate the variance of the carbon stock in each forest stratum and to calculate the number of permanent plots required for a more detailed inventory. For the pilot inventory, it laid 8 to 20 circular plots randomly in each stratum of the CHAL. From these findings, it selected a total of 300 permanent sample plots for the detailed forest carbon assessment of three main carbon pools - above ground (trees, sapling, shrubs, herbs and grasses and litter), below ground, and soil carbon. Through regular monitoring, the study team maintained Quality Assurance (QA) and Quality Control (QC). It did the data analysis using MS excel and R-program in order to present the data in tabular forms, diagrams, and figures.

Forest Strata: Overall, the study findings categorized the forest area (744,868 ha) of CHAL into four strata: dense broadleaf forest (208,400 ha), dense needle-leaf (173,329 ha), sparse broadleaf (204,321 ha), and sparse needle-leaf forests (158,818 ha). An area of 11,000 ha of forest that is up to 5 km buffer distance from the project area was identified as a possible leakage belt, where deforestation might increase due to REDD+ activities in the project area.

Socio-economic Groups: The study shows that diverse socio-economic groups inhabit the CHAL area. These groups depend heavily on forest resources for their food, household energy, and livelihoods. The total human population of about 4.3 million is increasing at an average annual rate of 0.41% over the past decade (CBS, 2011). The average family size is 4.21 individuals. Agriculture and tourism are the main economic activities, and 72.4 % of households depend solely on the forests for their household energy, so the pressure on the forests is increasing.

[1] Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.

Land Use Changes: The analysis of land use changes shows that CHAL lost 227.07 km^2 of forest from 1978 to 1990 and another 114.28 km^2 of forest from 1990 to 2000. However, there was a gain of 57.42 km^2 of forests from 2000 to 2010, so the overall net loss of forest area in the CHAL from 1978 to 2010 was -283.93 km^2. The deforestation rate was highest in Gorkha and Gulmi districts and the lowest in Mustang and Manang districts. The main causes of deforestation and forest degradation in CHAL are the unsustainable cutting of firewood and timber, overgrazing by livestock, lopping trees for fodder, soil erosion, and landslides, and forest fires.

Tree Species: The forest carbon assessment recorded 145 tree species in the CHAL. The dominant species are Sal (Shorea robusta), Chilaune (Schima wallichii), Khote sallo (Pinus roxburghii), Katus (Castanopsis indica), Gobre sallo (Pinus wallichiana), Utis (Alnus nepalensis), Gurans (Rhododendron arboretum), and Mahuwa (Engelhardia spicata).

Size of Trees: The average tree diameter is 18 cm and height of the trees is 12.1 m. Based on their diameter, a very high proportion of the trees are young individuals with a small diameter. Of the total trees, 45.4% have a Diameter at Breast Height (DBH) of 10-20 cm, 21.17% are 20-30 cm DBH, 9.57% are 30-50 cm, and 23.9% are >50 cm DBH. The average density per hectare in CHAL is 723 trees, 801 saplings, and 12,490 seedlings. The calculations showed that the mean tree basal area is 26.01 m2ha-1, tree stem volume is 64.69m3ha^{-1}, forest biomass is 231.7 t ha^{-1}, and carbon stock is 196.17 tC ha^{-1}.

Biomass: The total biomass in the study districts of CHAL is 172 million tons with an average of 231 t ha^{-1}. The dense needle-leaf forests provide 341.71 t ha^{-1} of biomass, dense broadleaf forests provide 274.12 t ha^{-1}, sparse broadleaf 165.79 t ha^{-1}, and sparse needle-leaf forest 145.37 t ha^{-1}. The forest biomass consists of tree biomass (above and below ground) 96.7%, leaf litter 1.45%, saplings 0.83%, shrubs 0.58%, and herbs and grasses 0.24%.

Carbon Stock: In CHAL, the total carbon stock in the forests is 540.1 million tCO_2e[2] (147.17 million tC) with an average of 725.9 tCO_2e ha^{-1}. The carbon stock was highest in dense needle-leaf forests with 898.6 tCO_2e ha^{-1} and lowest in sparse needle-leaf forests 524.8 tCO_2e ha^{-1}. Among the different carbon pools, the live carbon pool stored above and below ground is 399.6 tCO_2e ha^{-1}, of which trees provided 97%. The soil is also an important pool of carbon with an average of 320.3 tCO_2e ha^{-1}.

Carbon Sequestration Potential: The average annual potential for CO2 sequestration per hectare in the CHAL is 12.97 tCO_2e ha^{-1}. With its large area, the total annual potential in CHAL for CO_2 sequestration is 9.66 million tCO_2e (2.63 million tC). Within this total, the dense broadleaf forests give 31.5%, sparse broadleaf forests give 31.2%, dense needle-leaf forests give 19.4%, and sparse needle-leaf forests give 17.9%.

Conclusion and Recommendations: The findings of the study show that the condition of forests within the CHAL can be enhanced for greater carbon sequestration and other benefits, such as biodiversity conservation, livelihood improvement, and adaptation to climate change through the implementation of REDD+ project. The study suggests various activities in order to initiate REDD+ readiness initiatives in CHAL. These activities include:

- capacity building of local communities and other relevant stakeholders for periodic carbon measurement and establishment of a database at the subnational level for these measurements;
- addressing issues of permanency and leakage from the carbon pool due to deforestation by promoting livelihood and sustainable forest management activities for the local residents;
- ensuring participation of key stakeholders including government agencies, civil society organizations, and local communities for good governance with mechanisms for equitable distribution of the benefits;
- reducing dependency on forest resources for fuel, fodder, and timber by promoting alternative household energy sources and planting trees and grasses on available fallow land;
- reducing the use of forests for development infrastructures in coordination with different stakeholders including ministries and other government bodies, and
- promoting plantations and conservation programs including the selection of many appropriate tree species, in order to integrate REDD+ with other non-carbon benefits derived from the forests.

[2] Conversion factor: 1 tC = 3.67 tCO_2e

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Chapter 1

Background and Introduction

1.1 Background

Reducing emissions from deforestation and forest degradation along with conservation and sustainable management of forests in developing countries (REDD+) is emerging as an effective tool to mitigate and adapt to the impacts of climate change (Angelsen 2008; FAO 2011). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) estimated that the forest sector contributes 17.4% of all greenhouse gasses from human-caused sources; most of which is due to deforestation and forest degradation (IPCC 2007). Stern (2007) observed that curbing deforestation and forest degradation is a cost-effective way to reduce greenhouse gas emissions.

Based on scientific evidence, the Conferences of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COPs) after the 13th session (COP 13) in Bali, Indonesia outlined long-term cooperative action and called for enhanced national and international actions for operationalizing REDD+ to reduce greenhouse emission and address climate change adaptation and mitigation in developing countries.

The 15th session (COP 15) held in Copenhagen in December 2009 decided that US $ 30 billion should flow from the North (developed nations) to the South (developing nations). This flow of funds is intended to reduce emissions due to deforestation and forest degradation; generate other benefits such as livelihood improvement, poverty reduction, and biodiversity conservation; and build the adaptive capacity of ecosystems and local people in these countries. A consensus was reached during COP 15, that a number of safeguards should be designed and promoted both nationally and globally while undertaking REDD+ actions. This consensus later became an agreement during COP 16, held in Cancun, Mexico.

The COP 16 reached one of the most important breakthroughs in climate change negotiations (Kant *et al.* 2011), building a necessary foundation on which a more comprehensive structure for REDD+could be implemented in the future. The Cancun conference outlined three distinct phases for the REDD+ implementation process: readiness, demonstration, and implementation. It defined a phased implementation of REDD+ with the following steps:

i) development of national strategies or action plans, policies and measures, and capacity building;
ii) implementation of national policies, measures, strategies or action plans for further capacity building, technology development and transfer, and results-based demonstration activities, evolving into;
iii) results-based actions to be fully measured, reported, and verified.

Finally, the agreements request that when parties are developing their national action plans or strategies for REDD+, they address "the drivers of deforestation and forest degradation, land tenure issues, forest governance issues, gender considerations and the safeguards" to ensure effective and full participation of the relevant stakeholders, including indigenous peoples and local communities.

Decisions on REDD+ from COP 17, held in Durban, South Africa, related to financing options, safeguards, and guidance on reference levels and/or reference emission levels. These form benchmarks for measuring forest-related emissions per year as essential markers of environmental integrity when assessing future performance. These actions provided a strong basis for a robust Measurement, Reporting, and Verification (MRV) scheme, essential for the development of REDD+. COP17 decided that reference levels should be consistent with each country's greenhouse gas inventories, referring to anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks. The decision provides guidance for a transparent, flexible approach, in which reference levels are periodically reviewed in consideration of any advancement in methodologies; and sub-national reference levels can be interim measures while transitioning to a national level.

During COP 18, held in Doha, Qatar, were the main topics of debate on REDD+ where REDD+ financing and technical issues regarding MRV to be addressed under the Subsidiary Body for Scientific and Technological Advice (SBSTA). These issues included:

(i) how to design national forest monitoring systems;
(ii) how to create an appropriate MRV framework for result-based payments;
(iii) how to link MRV with reference levels;
(iv) the need for additional guidance on designing REDD+ safeguards and
(v) the drivers of deforestation.

The COP 19, held in Warsaw, Poland, decided upon the Warsaw framework for REDD+ that includes modalities for national forest monitoring systems; MRV; technical assessment of proposed forest reference emission levels/forest reference levels (RELs/RLs); safeguards information systems; and addressing the drivers of deforestation and forest degradation. According to the Warsaw framework, a developing country party may nominate a national entity to obtain and receive results-based payments (UNFCCC 2013). This national entity will be responsible for the effective implementation of REDD+ at the national level.

In the context of implementing COP agreements at the national level, the Government of Nepal (GoN) through its Ministry of Forest and Soil Conservation (MoFSC) has been preparing for REDD+ initiatives since 2008. As of 2015, Nepal is in the first phase, the readiness phase within which the GoN is developing a national REDD+ strategy and building the capacity of forestry stakeholders.

Nepal's REDD Preparedness Plan (RPP) 2009 envisions a hybrid approach including both a robust and comprehensive MRV framework at national and sub-national levels for implementing REDD+. Similarly, MoFSC through the REDD Implementation Center (REDD-IC) is implementing an emission reduction program with support from the Forest Carbon Partnership Facility of the World Bank (FCPF) in twelve Terai districts of Nepal.

Various civil society organizations are piloting REDD+ projects at the sub-national level in different parts of Nepal. The first REDD+ pilot project was implemented by a consortium of ANSAB, ICIMOD, and the Federation of Community Forest Users in Nepal (FECOFUN) in three sub-watersheds of Nepal with financial assistance from the Norwegian Agency for Development Cooperation (NORAD). Similarly, WWF Nepal developed a baseline of forest carbon for implementing REDD+ in the Terai Arc Landscape (TAL) and RECOFTC (The Center for People and Forests), and Nepal Federation of Indigenous Nationalities (NEFIN) conducted pilot projects to build capacity on REDD+. All these initiatives contributed to the ongoing national REDD+ process by providing lessons in determining reference level/reference emission levels, and implementing methodologies for measuring forest carbon and mechanisms for sharing benefits.

Since 2011, WWF Nepal, CARE Nepal, FECOFUN, and the National Trust for Nature Conservation (NTNC) have been implementing the five-year Hariyo Ban Program. The program covers two landscape areas: CHAL area running from north to south in the middle of the country and the Terai Arc Landscape (TAL). Both landscapes have diverse habitats and species of flora and fauna. However, the habitats are vulnerable to human disturbances at different scales and intensities. One objective of the Hariyo Ban Program is to build the structures, capacity, and operations necessary for effective and sustainable management of CHALs, including readiness for REDD+.

In order to implement REDD+ in CHAL, it is essential to establish a baseline of the socio-economic conditions and forest carbon stock to design successful REDD+ project activities in the future. When properly designed, REDD+ schemes can provide a sound bridging mechanism in the transition towards a low-carbon economy and ensure the ecological, economic, and socio-cultural integrity of the region. They can contribute to improving rural livelihoods, promoting good forest governance, delivering biodiversity objectives, and increasing resilience and adaptive capacities to climate change.

With this perspective, WWF Nepal commissioned this study through a competitive bidding process. It awarded the study to ANSAB and its partners for the study, ICIMOD and UNIQUE Forestry and Land Use GmbH, Germany.

1.2 Goal and Objectives

The goal of the study was to assess the baseline of forest carbon stock and the carbon sequestration potential of forests in CHAL, in order to initiate REDD+ readiness activities for the benefit of communities and conservation. The specific objectives of the study are to:

- Conduct surveys and establish baselines of forest coverage of CHAL and identify gaps,
- Assess carbon sequestration potentials, carbon capture, permanency, leakage, risks, and degradation of the forests in CHAL, and
- Build capacity of local communities and academia on forest carbon assessment.

1.3 Organization of the Report

Chapter 1 covers the background, rationale, and objectives of the study. Chapter 2 describes the study area in terms of physiography, socio-economic situation, land use, geology, and environmental condition. Chapter 3 provides details on the methodology, including study and sampling design, field arrangements, field inventory and analysis, and quality assurance and quality control measures adopted during the study. Chapter 4 presents results of the study and discussion, and Chapter 5, the conclusion and ways forward.

Jumdanda Jhapri CFUG, Jumdanda, Tanahu

Chapter 2

An Overview of Study Area

2.1 Location and General Characteristic

The CHAL area is located in central Nepal covering a geographical area of 31,854.4 km^2. The total forest and shrub area is 13,187.4 km^2. CHAL is located between 27˚35” and 29˚33” N latitude and 82˚88” and 85˚80” E longitude. Its topography is rugged with extreme altitudinal variation ranging from about 200 m above sea level to 8,091 m (Mount Annapurna). Part of CHAL falls within the Sacred Himalayan Landscape (SHL), which stretches from Bhutan in the east to Nepal’s Kali Gandaki River in the west.

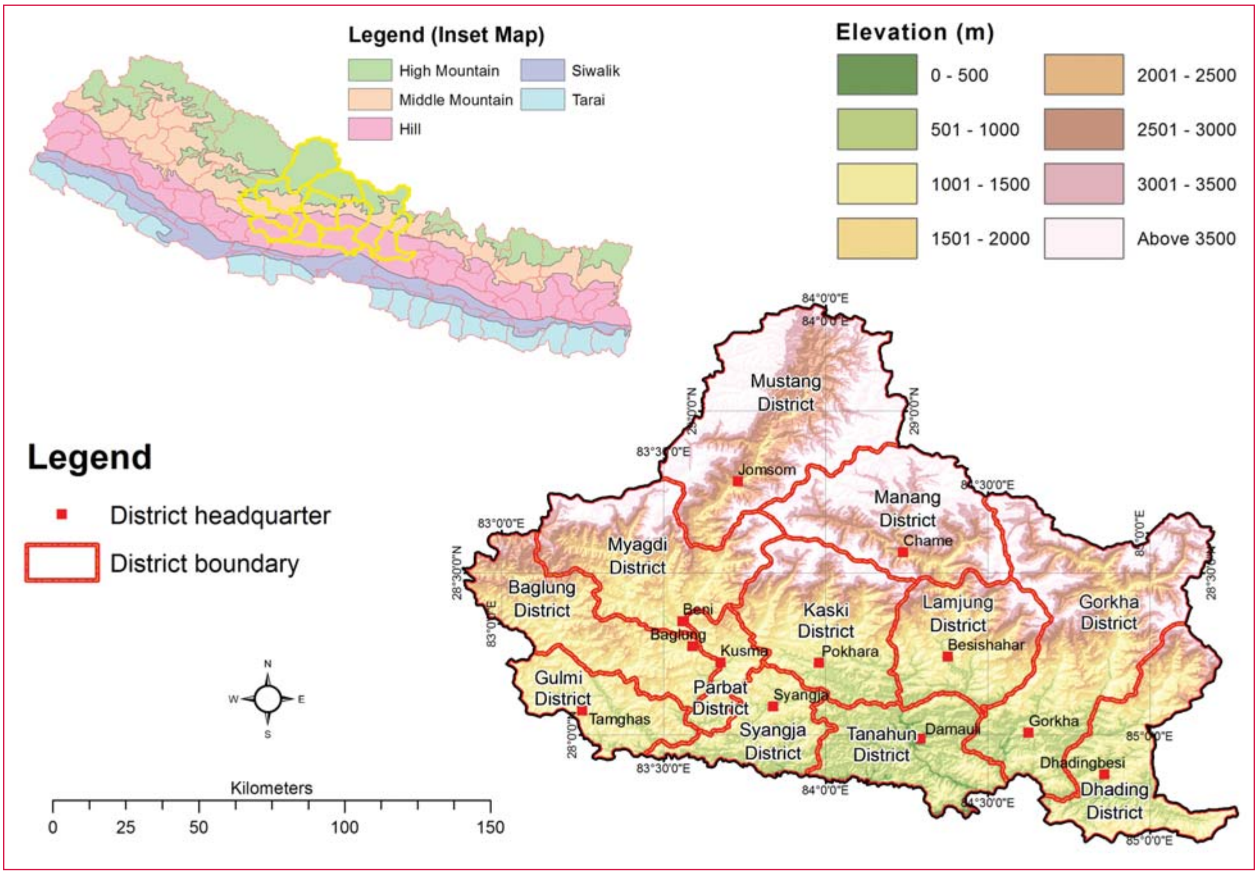
Bounded on the west by the Gandaki river basin, CHAL is a region of scenic beauty with the rain shadow of the trans-Himalayan area and snowcapped mountains of Annapurna, Manaslu, and Langtang in the north. The terrain descends southwards to the mid-hills, Churia range, and the flat lowlands of the Terai. It has seven major sub-river basins: Trishuli, Marsyangdi, Seti, Kali-Gandaki, Budi-Gandaki, Rapti, and Narayani. The nineteen districts covered by CHAL are Dhading, Nuwakot, Rasuwa, Chitwan, Tanahu, Lamjung, Gorkha, Manang, Mustang, Kaski, Syangja, Parbat, Makwanpur, Myagdi, Baglung, Gulmi, Palpa, Nawalparasi, and Argakhanchi.

CHAL covers four physiographic zones of Nepal: Siwaliks covering 11.4% of the CHAL, Middle Mountains 37.8%, High Mountains 18.7%, and High Himal 32.1%. Table 1 shows the physiographic zones and diverse climates in CHAL, which range from subtropical in the lowlands of Chitwan and Nawalparasi to alpine in the high mountains, to cold and dry in the Trans-Himalayan region. Due to its varying topography and climatic conditions, CHAL is one of the key study areas in Nepal for biodiversity and water resources. It has the most important habitat of the Snow Leopard and the Red Panda in the high mountains. The fact that black bear and common leopard live from north to south throughout the CHAL shows the north to south connectivity of CHAL.

Table 1: Physiographic zones in CHAL

Zone	Coverage (ha)	Percent coverage (%)
High Himal	1,029,239	32.1
High Mountains	599,849	18.7
Middle Mountains	1,210,954	37.8
Siwaliks	365,667	11.4
Total	**3,205,709**	**100**

Source: CHAL Rapid Assessment Report, 2013



Map 1: Map showing study districts of the CHAL

This study covers twelve districts in CHAL: Baglung, Dhading, Gorkha, Gulmi, Kaski, Lamjung, Manang, Mustang, Myagdi, Parbat, Syangja, and Tanahu. Map 1 shows the study districts. WWF Nepal has done a detailed survey for TAL and SHL that already covers the remaining seven districts of Arghakanchi, Palpa, Nawalparasi, Makwanpur, Rasuwa, Nuwakot, and Chitwan.

2.2 Land Use, Geology, and Soil

The CHAL has diverse land use types. Forest covers the largest portion of CHAL, followed by agriculture, sand/bare land, snow/ice covered areas, grasslands, and alpine meadow (Table 2).

Table 2: Areas with different land use/ land cover in 1990, 2000 and 2010

Land Use Class	1990		2000		2010	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	1,133,621	35.4	1,137,718	35.5	1,136,709	35.6
Alpine meadow /scrub	275,518	8.6	252,863	7.9	260,682	8.1
Grasslands	329,662	10.3	334,084	10.4	276,634	8.6
Agriculture	663,505	20.7	675,471	21.1	677,456	21.1
Snow/ice	286,467	8.9	469,907	14.7	304,150	9.5
Sand/bare soil	484,108	15.1	303,838	9.4	517,110	16.1
Water	32,829	1.0	32,829	1.0	32,696	1.0
Total	**3,205,710**	**100**	**3,206,710**	**100**	**3,205,437**	**100**

Source: CHAL Rapid Assessment Report, 2013

The geological composition of CHAL varies across the physiographic zones. The total thickness of the rock strata in the Kaligandaki basin sequence is 6,000 m to 7,000 m. This sequence has lower, middle, and upper sections. The thickness of the rock strata increases continuously from the lower sequence that is 1,400 m thick, to 3,500 m and 3,000 m in the middle and upper sequences, and 5,000 m thick in the Marsyangdi basin (Le Fort 1975).

The major rock types are schist, gneiss, marble, and quartzite in the Kaligandaki section. The Trishuli Basin in the Nuwakot complex has no crystalline rocks. The Nuwakot complex has only pelitic and calcareous meta-sediments of low metamorphic grades (Stocklin and Bhattarai 1977), rarely exceeding sericite chlorite grade. The age of the complex ranges from Late Precambrian to Late Paleozoic (LRMP 1986).

The geology of the Trans-Himalayan region north of the Himalaya is fragile with formations of alluvial, colluvial, and morainal deposits and steep mountainous terrain (LRMP 1986). Key fossils in evolutionary biology, ammonites (saligram) and fossilized mollusks, are common in this region (Upreti *et al.* 1980). The age of rocks in the high Himalaya is Precambrian to Mesozoic. Radiometric dating suggests that the granite found in this region intruded into the other rock strata during the Tertiary period (MoEST 2008). The geology of the high mountains and mid-hills is relatively stable, compared to other physiographic zones, because the rocks are mainly gneiss, quartzite, mica schist, phyllites, limestone, and some granite (MOEST 2008). The inner valleys of the Marsangadi, Madi, Seti, and Trisuli Rivers are of stable, older alluvial deposits, which are suitable for crop production.

The dominant soil in the high Mountains and Siwaliks generally has sandy to sandy-loam texture with low fertility and shallow in depth. The highly rugged mountainous terrain coupled with high monsoon rains has resulted in a high level of soil erosion and loss of nutrients. The soil in the mid-hills is moderately to slightly acidic, medium to light-textured, coarse-grained, sand to sandy-clay-loam. The more stable landscapes, such as the valleys and flat areas in the mid-hill have silty-clay-loam (Pokhara Valley) to fine-textured clay soils (Raignas tar, Lamjung and Madi Valley, Palpa). The river valleys have alluvial deposits, with sandy-clay-loam to loamy texture, which are highly suitable for agriculture.

2.3 Climate

CHAL has a variety of climates ranging from cold alpine semi-desert (in the trans- Himalayan zone of upper Mustang) to sub-tropical humid in the lowlands of the Siwaliks (Table 3). This range is due to extreme variations in elevation and topography from north to south across CHAL. Three major factors influence the climate: the Himalaya mountain range, monsoons, and westerly disturbances.

CHAL has four distinct seasons: pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and winter (December-February) (WECS 2011). The average reported minimum and maximum temperatures are 4.9°C and 39.9°C. The mean temperature is above 25°C in the Siwaliks, about 20°C in the Middle hills, and between 10°C to 20°C in the high mountains (MoE 2011). The average annual rainfall ranges from 165 mm at Lomanthang (Mustang) to 5,244 mm at Lumle, in Kaski, which is the highest rainfall in the country. Orographic effects due to rainshadows cause significant spatial variations in the level of precipitation across CHAL. Nearly (80%) of the total annual precipitation occurs during the monsoon season from June to September (Practical Action 2010).

The small amount of winter precipitation comes as occasional, short rainfalls in the Siwalik and Middle-hills, and as snowfall in high altitude areas. The winter snowfall in the Himalaya is important for generating sufficient volumes of spring and summer meltwater, which is crucial for agricultural irrigation in the lower hills and valleys.

Table 3: Climate in different physiographic zones

Physiographic zone	Climate	Average annual precipitation (mm)	Mean annual temperature (^{0}C)
High Himal and High Mountains	Arctic/alpine/sub-alpine	150-200	<3-10
Middle Mountains	Cool/ warm	275-2,300	10-20
Siwaliks	Tropical/sub-tropical	1,100- 3,000	20-25

Source: WECS, 2011

2.4 Forest Management Regimes

There are six types of forest management regimes in CHAL: protected areas, government-managed forests, protection forests, community forests, leasehold forests, and buffer zone community forests. Of CHAL's total forest area, about 29% is under community-based management regimes – community forestry, leasehold forestry, and buffer zone community forestry (DoF 2012) and a small area of forest (461 ha) is owned privately (Table 4). The government manages the remaining forest, which is spread across CHAL.

Table 4: Types of forest in 12 CHAL districts

District	Forest Type							
	Community Forest			Leasehold Forest			Private Forest	
	Area (ha)	No. of FUGs	HH	Area (ha)	No. of FUGs	HH	No.	HH
Dhading	25,241	628	64,799	1,723	430	3,785	13	9.3
Gorkha	21,480	447	53,333	583	186	146	14	26.4
Lamjung	19,334	304	24,825	366	110	907	29	8.7
Tanahu	33,229	513	50,097	1,889	455	331	12	7.2
Syangja	10,554	423	45,046	82	8	82	15	10.6
Kaski	14,680	421	35,451	0	0	0	0	0
Manang	6,738	19	1,128	0	0	0	0	0
Myagdi	19,885	256	29,763	0	0	0	5	1.4
Parbat	11,815	351	40,069	0	0	0	11	8.4
Baglung	11,727	332	40,892	4	2	14	1	0.8
Gulmi	14,751	363	52,913	71	7	71	1	0.2
Total	**189,434**	**4,057**	**438,316**	**4,718**	**1,198**	**5,336**	**101**	**73**

Source: Department of Forest 2011/12

2.5 Demography and Socioeconomic Status

In 2011, the total human population of CHAL was about 4.3 million and increasing at an average annual rate of (0.41%) over the last decade (CBS 2011). The average family size was 4.21, which is lower than Nepal's average of 4.7. Twelve of the nineteen districts in CHAL had negative population growth in the last decade: Dhading, Nuwakot, Rasuwa, Lamjung, Gorkha, Manang, Mustang, Syangja, Parbat, Myagdi, Gulmi, and Argakhanchi. The main reason is likely out-migration from mountains to valleys and inner Terai in search of better livelihood opportunities. According to the 2011 census data, the total population in the twelve studied districts was 2,708,380 on 23,487 km^2 of land.

The main economic activities include agriculture and tourism. However, remittances contribute almost half (46%) of the average household income and have become the most powerful economic force transforming rural life and livelihoods. The other main sources of income for rural households are agriculture (including livestock), salaried jobs, tourism related business, forestry, and wage labor. The high level of inequality in access to land compels the poor to look for alternatives to farming, usually as laborers in cities or abroad. The participation of women and other marginalized groups in natural resource management and other community development activities has been increasing over the years. Yet, there are still gaps in the process of participation, in assigning clear roles and responsibilities, in the transparency of work, and inequitable benefits sharing.

Chapter 3

Study Methodology

This study report includes socio-economic, geospatial analysis, and biophysical survey data to create a baseline of the socio-economic conditions and forest carbon stock in CHAL. The detailed methodologies for assessing socio-economic and biophysical conditions of the area are described below.

3.1 Socio-Economic Baseline Survey

3.1.1 Literature review

The study team collected most demographic information from the population census report published by the Government of Nepal in 2011. The team also reviewed district profiles of respective districts, and annual and periodic reports published by the District Development Committee (DDC), District Forest Office (DFO), District Education Office (DEO), District Agriculture Development Office (DADO), District Soil Conservation Office (DSCO), etc. These reports contained information relating to land uses, land holdings, productivity, population, professions, and forest management practices in the twelve selected districts. Similarly, the team reviewed a rapid assessment report of CHAL conducted by Kathmandu Forestry College for Hariyo Ban Program to extract relevant information. The study team reviewed similar socio-economic baseline reports produced by WWF for the Sacred Himalayan Landscape (SHL) and by ANSAB for three watersheds -- Kayarkhola-Chitwan, Ludikhola-Gorkha, and Charnawati-Dolakha, of which the first two fall within CHAL.

3.1.2 Focus group discussion

The team conducted 58 focus group discussions (FGDs) in the twelve districts selected for the study -- five FGDs each in ten districts and four FGCs each in two districts. The team collected information on agricultural production, consumption demand, and supply of forest products (timber and NTFPs). The study also identified and prioritized the drivers of deforestation and forest degradation in CHAL. The FGD participants were people from the selected villages who depend on the forests, including women, Dalits, indigenous people, local teachers, and local leaders.

3.1.3 Key informant interview

The team conducted 15-20 key informant interviews in each selected study district with local teachers and leaders; representatives of different forest management regimes; forest resource harvesters, processors, and traders; and local experts working in the forestry and agriculture sectors. The interviews focused on getting information on existing forest management, agricultural practices and issues, or drivers of deforestation and forest degradation in CHAL.

3.1.4 Consultation with district level stakeholders

The study team organized regional and district level consultation workshops to verify and triangulate the information obtained in the literature, FGDs, and key informant interviews. It consulted DFOs, District Livestock Service Offices (DLSO), DADOs, DDCs, district FECOFUN branches, local NGOs, and Hariyo Ban Program teams. The consultation focused on issues associated with land use changes and opportunities for conserving and enhancing forest carbon in different regimes for forest management in CHAL.

3.2 Geospatial Assessment for Baseline of Forest Coverage of CHAL

The first and most crucial step was to identify the study area for the baseline assessment of forest carbon for REDD+ implementation in CHAL. A clear boundary is required to verify the data and to avoid overlap and double counting between neighboring/nearby inventories. First, the team defined the spatial boundaries of CHAL to facilitate accurate measuring, monitoring, and verification. Secondly, they used GIS software to distinguish spatial boundaries like rivers or creeks and mountain ridges.

3.2.1 Satellite data analysis

The study team used a combination of satellite data, GIS data, and relevant GIS software to identify and distinguish the project area, to recognize the forest areas within the project areas, and to classify forests within the study area.

Time series of Landsat satellite imagery is freely available and a valuable tool for monitoring ecosystem change (Xian *et al.* 2009; Vogelmann *et al.* 2012), forest cover (Bhattarai *et al.* 2009; Qamer *et al.* 2012; Townshend *et al.* 2012; Niraula *et al.* 2013), agricultural yields (Abtew and Melesse 2013; Lyle *et al.* 2013), and urban growth (Yuan, 2005). Hansen and Loveland (2012) used Landsat imagery and monitoring products to review the land cover change in a number of large areas.

The present study used Landsat images (each scene 185 x 185 km), which were ortho-rectified and cloud free Multispectral Scanner (MSS) and Thematic Mapper (TM), to map land/forest cover, detect and simulate changes, and stratify the forests plots. It downloaded the images from the USGS-EROS archive (Annex 1 and 2). All spectral bands of Landsat were co-registered geometrically, but metadata was used for reflectance to radiance conversion, gains, offsets, solar irradiance, solar elevation, and acquisition date/time given in the image. From the satellite images, the team extracted Normalized Difference Vegetation Index (NDVI), Land Water Mask (LWM), Normalized Difference Snow Index (NDSII), and Soil-Adjusted Vegetation Index (SAVI) to classify the images. For topographic information, the team used the Advanced Spaceborne Thermal Emission and reflection Radiometer (ASTER) with 30m horizontal resolution and the Global Digital Elevation Model (GDEM), add-on products, such as slope and aspect. For future forest monitoring, the team acquired selected pockets of WorldView-2 (0.5m) and CARTOSAT-1 (2.5m) satellite images.

The team acquired digitally scanned and extracted layers of the topographic sheets from National Geographic Information Infrastructure Project (NGIIP), Department of Survey (DoS), Nepal To prepare base data layers. The data layers correspond to topographic sheets of scale 1:25,000/50,000 based on 1996 aerial photographs for western Nepal published since 1995. The datasheets were combined to generate Geographic Information System (GIS) format layers of contours, settlements, roads, trails, and streams. These datasets were used to prepare the GIS maps to assess and map forest resources and forest carbon stock.

This study used ERDAS imagine and eCognition developer software for object-based image analysis. ArcGIS was used for GIS operations and map formation. Microsoft office and other statistical packages were used for the write-up and statistical analysis.

3.2.2 Pre-processing satellite images

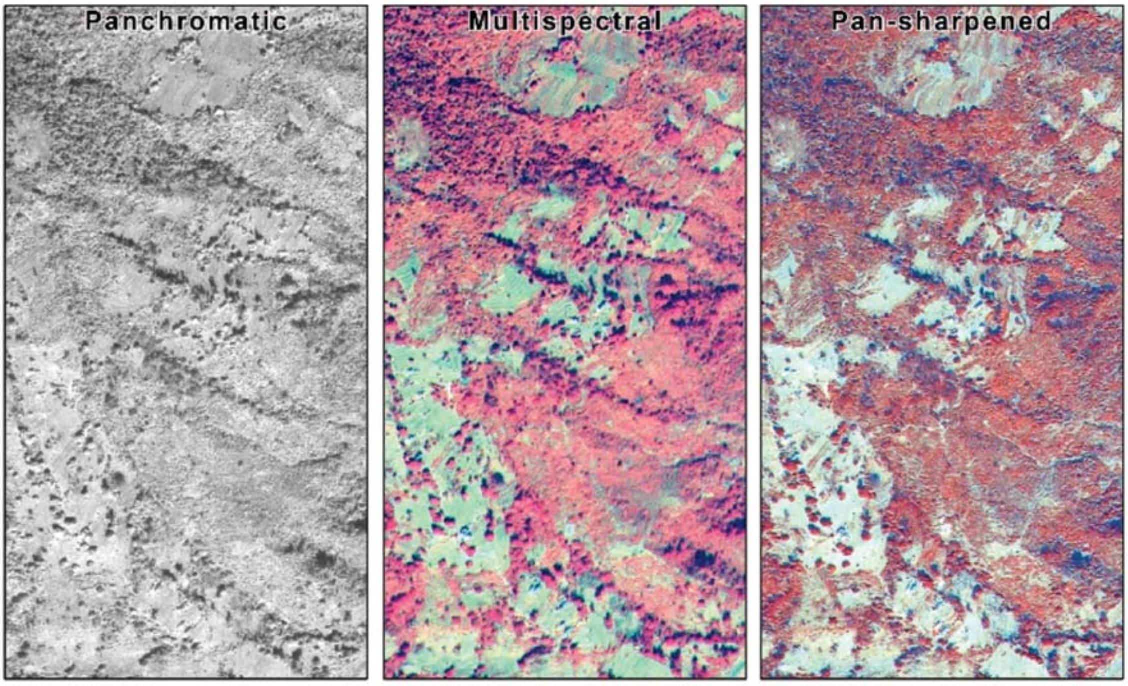
3.2.2.1 Layer stacking and spectrally image enhancement

Layer stacking is the process of “stacking” images from the same area together in order to form a multilayer image. For layer stacking, ortho-rectified and cloud-free images of the multispectral scanner (MSS) and Thematic Mapper (TM) with individual bands extracted and stacked respective row and path spectral bands. Most of the area (95%) is present in zone 44 of Universal Transverse Mercator (UTM) coordinate system, World Geodetic System (WGS) 84.

Image enhancement is the technique by which the low contrast of satellite images is improved to make the image more interpretable. 'Standard deviation stretch' is the algorithm to enhance image contrast and the spectral behavior of the satellite imageries. The magnitude of the enhancement depends on the standard deviation value defined by the analyst. The study team used the 'Standard deviation stretch' algorithm to improve the image contrast to identify the classes (Hashimoto *et al.* 2011). This study used an interval value between –2.5 to +2.5 standard deviations from the mean of the existing pixel values. This stretched the values to the complete range of output screen values. In addition, the study used the contrast brightness utility of ERDAS IMAGINE to enhance visual details of the satellite images.

3.2.2.2 Resolution merge – worldview-2

This study obtained ortho-rectified WorldView-2 very high-resolution satellite imagery, which is the first commercial high-resolution satellite imagery to provide eight spectral bands (coastal blue, blue, green, yellow, red, red edge, NIR1, and NIR2) with 2 m spatial resolution and panchromatic 0.5 m spatial resolution. The study team fused 2 m resolution and panchromatic imagery of 0.5 m resolution to get a pan-sharpened image of 0.5 m spatial resolution using Hyper-spherical Color Sharpening (HCS) technique, bilinear interpolation resampling technique, smoothening filter size 5, and unsigned 16-bit output data type (Map 2). Padwick *et al.* (2010) found that HCS algorithm maintains the best balance between spectral and spatial quality imagery when comparing the four algorithms -- HCS, Hue Intensity Saturation (HIS), Principal Components Analysis (PCA) and Gramm-Schmidt (GS).

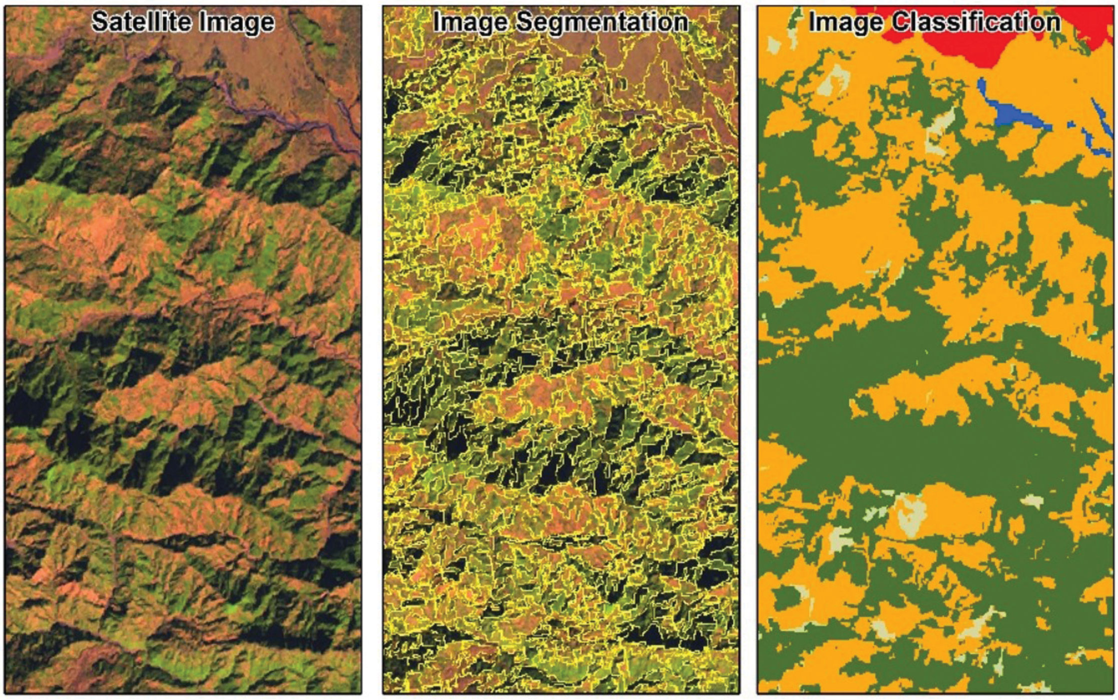


Map 2: A sample of spatial resolution fusion

3.2.3 Land cover/forest cover change assessment and simulation

3.2.3.1 Satellite images segmentation and classification

For classification of Landsat satellite images, the team used the Geographic Object-Based Image Analysis (GEOBIA) classification technique in eCognition Developer. GEOBIA provides a methodological framework for the machine-based interpretation of complex classes defined by spectral, spatial, contextual, and hierarchical properties. It yields better classification results with a higher degree of accuracy than pixel-based methods (Blaschke *et al.* 2008; Duro *et al.* 2012). The basis of object-based image analysis is the segmentation of satellite images, and there are several algorithms that can be used to do this. The present analysis used the multi-resolution segmentation algorithm to develop image objects (Hay *et al.* 2003) based on homogeneity criterion using the parameters shape =0.1, compactness =0.5, and scale =16 (Map 3).



Map 3: A sample view of satellite image segmentation and classification

The team selected a minimum of ten reference segments for each class, using field verification and very high-resolution satellite information to develop the rules.). The team chose image metrics for a given class according to their relative importance and potential to delineate the class. It fixed thresholds for each metric iteratively by visual analysis using bi-spectral plots and validating with reference segments. The rules with (90%) class separability (based on reference segments) were chosen to apply over the entire scene. The team ascertained the class separation using the segment-based approach, then made a map of land cover classifications for each scene. After finalizing of the classification of each scene, the team mosaiced all the classified scenes together to create a land cover map of the twelve districts. Figure 1 shows the overall methodology of satellite image classification.

3.2.3.2 Accuracy assessment

A team of internal experts, who had not participated in the classification process, provided an independent assessment of the land cover products. The final classified product was subjected to classification accuracy using 130 GPS-tagged field validation points and 435 Google Earth derived reference points for the entire country LC-2010. For most places, the Google Earth platform offers very high-resolution satellite imagery, which is widely used for the validation of classified land cover products (Cohen *et al.* 2010; Gong *et al.* 2012; Olofsson *et al.* 2013).

3.2.4 Stratification of forest area

First, the study team acquired, processed, and analyzed the high-resolution satellite images, then; it collected basic information on land use, land cover, vegetation, and topographic data for the project area. This information was geo-referenced and traced onto a base map with details of the project area, by showing the different land-use categories like forest, water bodies, open land, agriculture land, etc. The team classified the forested areas of the project area into four relatively homogeneous strata using high-resolution remote sensing imagery and the land cover map of 2010:

- Sparse Needle-leaf (SN)
- Dense Needle-leaf (DN)
- Sparse Broadleaf (SB)
- Dense Broadleaf (DB)

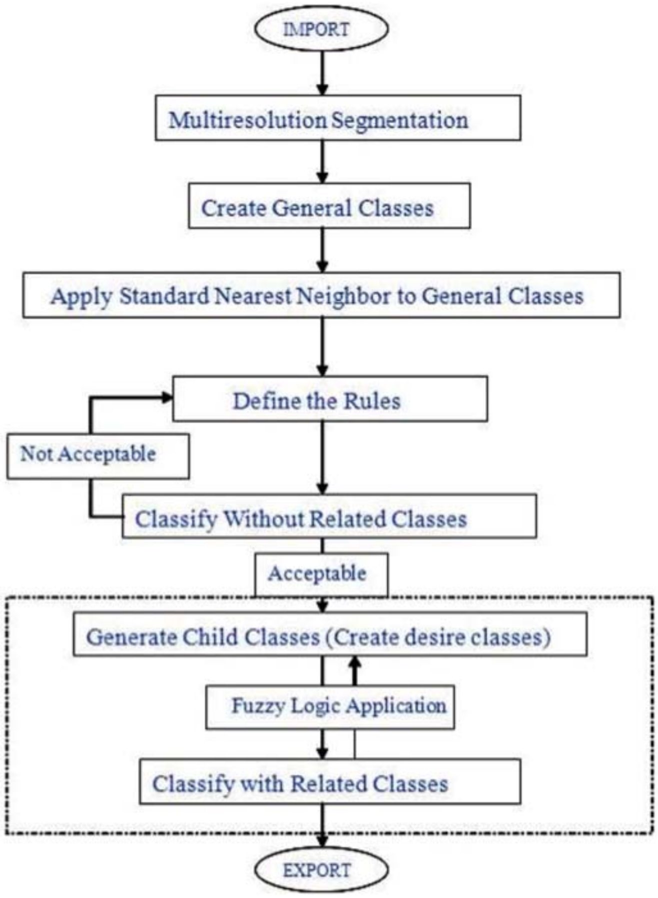


Figure 1: Flow chart of object-based image classification

Photograph 2 (2a, 2b, 2c, 2d) shows the four broad strata and Table 5 presents area of four different strata in CHAL. The team regarded forest with canopy coverage of more than 40% as a dense forest and of 10-40% coverage as a sparse forest. Stratified random sampling techniques generally yield more precise estimates (MacDicken 1997) to measure the densities of ground-based carbon stock.

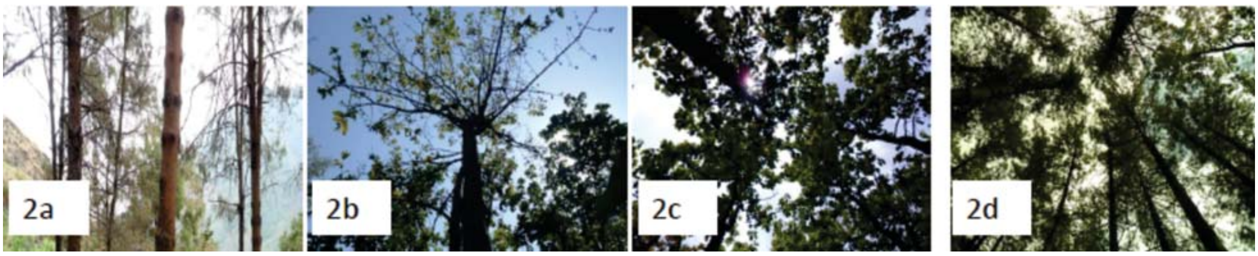


Table 5: Area of four different strata in the landscape

Stratum	Total area [ha]
Dense broad-leaf forest (DB)	208,400
Dense needle-leaf forest (DN)	173,329
Sparse broad-leaf forest (SB)	204,321
Sparse needle-leaf forest (SN)	158,818
Total	**744,868**

Source: GIS Analysis ICIMOD and ANSAB 2014

3.2.5 Identification and mapping of leakage belt

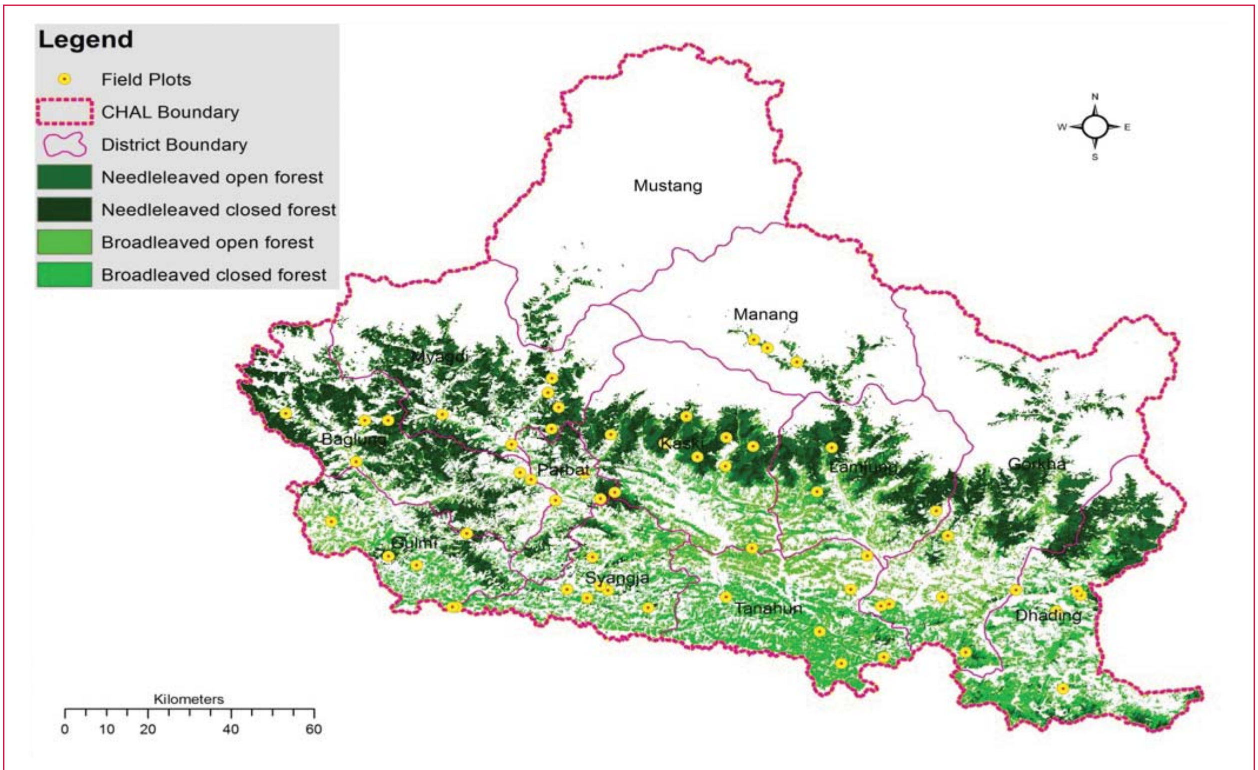
Leakage belt is defined as an area outside the project area with the potential for increased GHG emissions, which are directly attributable to the REDD+ project activities. The concept of a leakage belt recognizes that activities to reduce deforestation within the project area may increase deforestation or forest degradation outside the project area. For example, putting a strict restriction on the collection of fuelwood can increase fuelwood collection in the forests neighboring the project area. Another example -- if logging was happening within the project area previously, project actions could displace the logging to forests outside of the project area (Aukland *et al.* 2003).

The study team used FGDs, field observations particularly in the deforested area, and GIS analysis with high-resolution images to identify possible leakage belts outside the project area. The analysis mainly examined the east, west, and southern part of the Chitwan-Annapurna Landscape in areas within a five km buffer of the forest area. This methodology led to a correct demarcation of each leakage belt. This is crucial for accounting GHG benefits of a REDD+ project, which will monitor the area with leakage and deduct leakage from the actual Net Emission Reductions (NERs) in the future.

3.3 Forest Carbon Assessment

3.3.1 Pilot inventory for variance estimation

In the field, the team conducted a preliminary inventory to estimate the variance of the carbon stock in each forest stratum as a basis for calculating the number of permanent plots required for a more detailed inventory. For the pilot inventory, the team laid 8 to 20 circular plots randomly in each stratum and carried out measurements in 58 circular plots (stratum-wise detail is presented in Table 6). All the plots were distributed randomly using Hawth's Analysis Tools for Arc GIS (www.spatialecology.com) as the random selection is important to cover the natural variability within the different stratum. Map 4 shows the locations of the temporary plots laid out on the ground for the pilot inventory.



Map 4: Distribution of pilot sample plots on base map

Within the pilot inventory plots, the team measured the diameter at breast height (DBH), which is 1.3 m above the ground level, for all the trees above and equal to 5 cm in 20 sample plots in dense and sparse broadleaf forest and 10 and 8 plots in dense and sparse needle-leaf forest strata respectively. The shape of the pilot plot was circular, and the size was 750 m^2, with a horizontal radius of 15.45 m.

The team used Eq. (i) below to estimate the biomass on the basis of measured DBH, which is generally recommended for moist climates with annual rainfall (1,500 – 4,000 mm), as suggested by Brown *et al.* (1989, p. 886).

$y = 38.4908 - 11.7883DBH + 1.1926\,DBH^2$ ... Eq. (i)

The carbon fraction 0.47 was used to derive carbon stock per tree from the estimated biomass. Finally, the team estimated carbon stock per plot, per ha (tC ha^{-1}), and mean forest carbon stock per ha for each stratum.

For calculating tree carbon stocks (tC ha^{-1}) from the pilot inventories, the team estimated the total number of permanent sample plots required at stratum ( ) level by using Eq. (ii) (UNFCCC 2009, p. 4):

$$n_i = \frac{\sum_{h=1}^{L} N_i\,.st_i}{\left(N\frac{E_1}{Z^{\alpha/2}}\right) + \sum_{i=1}^{L} N_i\,.(st_i)^2}\,.N_i\,.st_i \quad \text{... Eq. (ii)}$$

Where,

L = total number of strata (dimensionless);
N_i = maximum total number of sample plots in stratum ;
st_i = standard deviation of *Q* for stratum ;
N = maximum possible number of sample plots in the project area;
E_1 = allowable 10% error of the estimated *Q* (expressed as fraction); and
$Z^{\alpha/2}$ = value of the statistics *Z* (embedded as inverse of standard normal probability cumulative distribution).

Next, the team estimated the mean carbon stock, the mean standard deviation, and the variance of the forest, based on the pilot inventory of the 58 random sample plots in the four different strata of CHAL. They calculated the total number of plots required based on the standard deviation and variance in the pilot inventory data (Table 6). Annex 3 presents a sample datasheet for a forest carbon inventory.

Table 6: Total number of permanent sample plots

Stratum	Total area under [ha]	Required no. of permanent inventory sampling plot (PISP)	Number of extra reserved plots	Total number of plots
DB	208,400	75	20	95
DN	173,329	43	10	53
SB	204,321	96	20	116
SN	158,818	28	8	36
Total	**744,868**	**242**	**58**	**300**

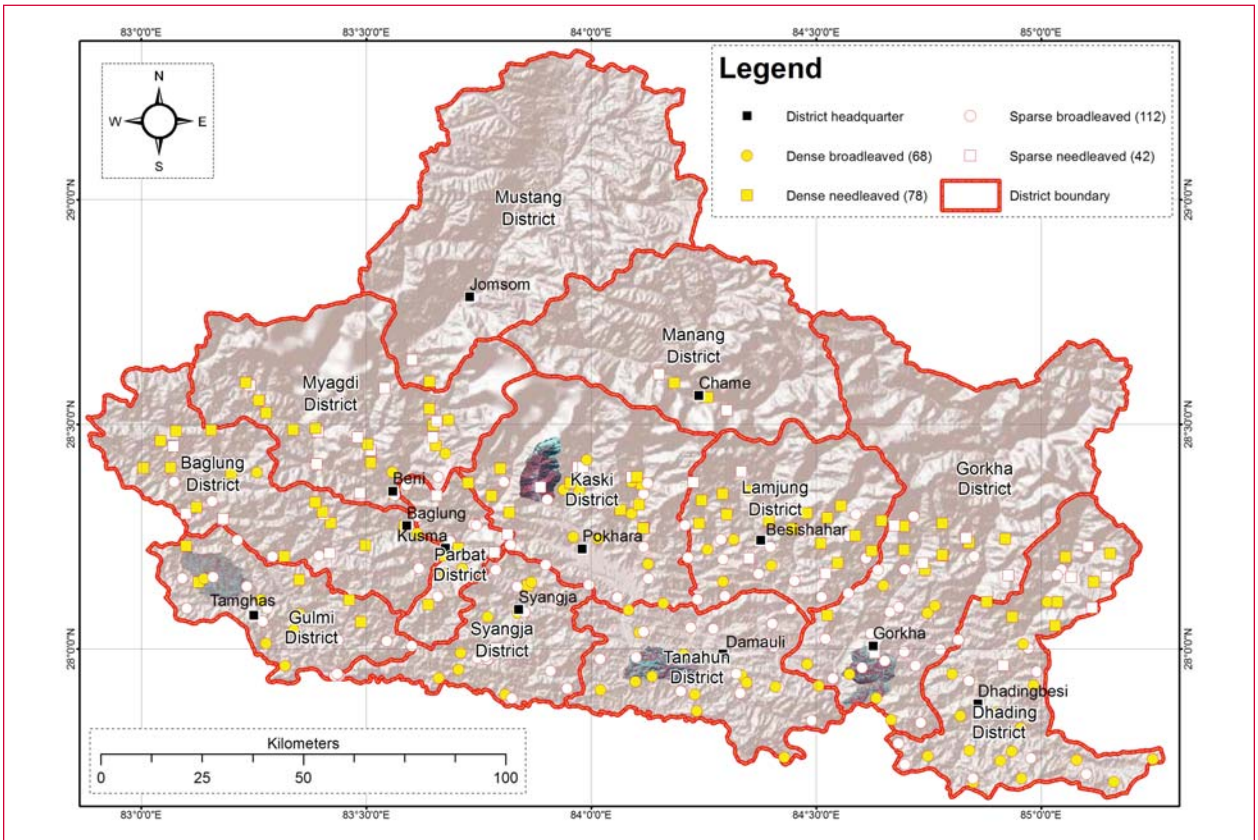
3.3.2 Permanent plot distribution and layout

The team established 300 concentric circular permanent plots within the four different forest strata to conduct the forest carbon assessment in the CHAL. The permanent plots were distributed randomly using Hawth's analysis tools for ArcGIS (www.spatialecology.com) (Map 5 and 6). The coordinates were loaded on a GPS set (GPSMAP 62s e 62nd, Garmin) to indicate a center of the nested concentric plots. Later, the team traversed the plots the field using GPS to fix a center point for each plot.

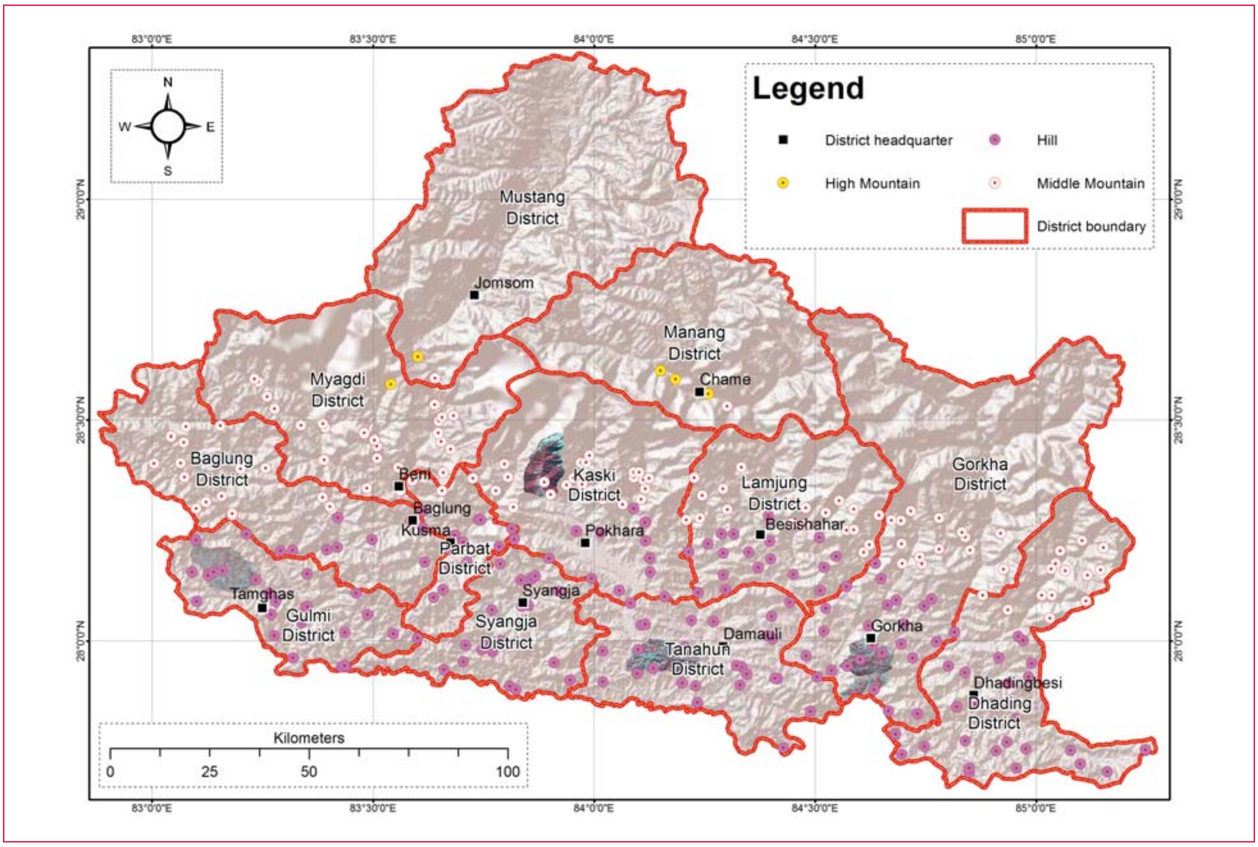
3.3.3 Forest carbon stock assessment

The methodology for forest biomass and carbon stock estimation follows a step-wise procedure, using internationally recognized standards for carbon inventory (Table 7). The procedure emphasizes the training of forest technicians, local resource persons (LRPs), university students, and other relevant stakeholders.

The team followed the guideline for forest carbon measurement developed by ANSAB under the NORAD-funded REDD+ pilot project to abide by the step-wise procedure for assessing biomass and carbon stock. The protocols in the guideline are based on the IPCC Good Practice Guidance (IPCC 2003, 2006) report, the Community Forestry Inventory Guidelines prepared by the Department of Forests GoN, and the standard procedures developed by MacDicken (1997).



Map 5: Distribution of field sample plots based on forest type



Map 6: Distribution of field sample plots based on physiographic regions

Table 7: IPCC Good Guidance Principle for Carbon Accounting (IPCC 2006)

Accurate and Precise	Accuracy is how close estimates are to the true value; accurate measurements lack bias and systematic error. Precision is the level of agreement between repeated measurement; precise measurements have lower random error
Comparable	Data, methods and assumptions applied in the accounting process must be those with widespread consensus and which allow meaningful and valid comparison between areas
Complete	Accounting should be inclusive of all relevant categories of sources and sinks and gases. If carbon pools are excluded, documentation and justification for their omission must be presented
Conservative	Where accounting relies on assumptions, values and procedures with high uncertainty, the most conservative option in the biological range should be chosen. Conservative carbon estimates can also be achieved through the omission of carbon pools
Consistent	Accounting estimates for different years, gases and categories should reflect real differences in carbon rather than differences in methods
Relevance	Recognizing that trade-offs must be made in accounting as a result of time and resource constraints, the data, methods and assumptions must be appropriate to the intended use of the information
Transparent	The integrity of the reported results should be able to be confirmed by a third party or external actor. This requires clear and sufficient documentation.

3.3.4 Planning and capacity building

The study team conducted various sessions of ‘hands on’ training on techniques of forest carbon stock assessment and field planning at the district and cluster level in various places of the CHAL, in order to ensure efficient and timely completion of the assigned task and consistency in the field measurement and collection of data. The participants included ANSAB’s forest technicians, consultant forest technicians from the Institute of Forestry (IoF) in Pokhara, and representatives from DFOs and FECOFUN chapters of the study districts. These forest technicians were the crew and principal technical persons who assisted in subsequent training and implementing the forest carbon stock assessment in the field.

3.3.4.1 Orientation and planning on forest carbon assessment

The orientation program, targeting the forest technicians, university students, and local forest user groups, aimed to improve the quality of the assessment outputs including cost, time, and usage of the available resources, and to develop a detailed field plan for the forest carbon assessment. The detailed field planning was conducted at the completion of the orientation so that all the forest technicians in the crew were involved. The planning focused on finding routes to the permanent sample plots that the team had already plotted on the stratified base map of CHAL; and calculating the number of days, cost, and required human resources to complete the forest carbon assessment in CHAL.

3.3.4.2 Capacity building of LRPs on forest carbon assessment

This study aims to increase the capacity of local communities and key stakeholders to carry out forest carbon assessment and make local communities aware of the concept, process, and applicability of REDD+ in the context of Nepal. Thus, a one-day orientation training on REDD+ and the process of forest carbon assessment was conducted at the cluster level for 217 representatives (88 female and 129 male) of different forest management regimes and FECOFUN branches. These representatives were encouraged to participate in the assessment process because they know their forests best. Among them, the team mobilized 84 as Local Resource Persons (LRPs) to carry out the forest carbon assessment.

3.3.4.3 Capacity building of key stakeholders on MRV

The team organized two regional level Monitoring, Reporting, Verification (MRV) training in Kaski and Damauli to build the capacity of representatives from the relevant stakeholders, including government, non-government organizations, and CBOs in MRV for REDD+. The objective of the training was to familiarize forestry stakeholders on REDD+, the MRV system, and required actions and the potential institutional framework to participate in carbon credit programs. Forest technicians and officers representing DFO, DISCO, DDC, and other civil society organizations participated the training. The participants learned both theoretical and practical knowledge and skill for planning, designing, assessing, and monitoring forest carbon and co-benefits to be included in MRV.

3.3.5 Equipment and materials

The equipment shown in Annex 4 was used to measure forest carbon pools. The equipment, data collection sheet, and other materials were developed, collected, and checked before initiating field measurement. This approach ensured that every instrument was functioning, and ready with a complete set and number of data collection sheets, equipment, and other materials.

3.3.6 Human resource management

The study formed five survey teams with six members in each. Each team had two forest technicians as leaders and four LRPs for the detailed assessment of forest carbon. Due to their training on REDD+ and the process of forest carbon assessment, the team members knew the measurement techniques, could operate all the equipment properly, and understood the importance of the details in the work.

Before initiating the assessment, the six teams again had orientations on the format for data collection, survey equipment, responsibilities of crewmembers, and the considerations for achieving higher accuracy and precision of the field measurements. Thus, the team had the enhanced knowledge and skill to ensure quality control. The team of LRPs and forest technicians were familiar with the project sites so could conduct the assessment effectively and efficiently. In addition, an experienced forest carbon expert backstopped the whole process and field survey teams in conducting the assessment process in CHAL.

3.3.7 Field measurements

3.3.7.1 Size and shape of sample plots

The field teams laid nested concentric circular permanent plots with horizontal radious ranging from 0.56 m to 15.45 m for quantifying different carbon pools. They used circular samples, which are easy to establish, especially in sloping terrain.

As shown in Figure 2, the study established several subplots within each plot for specific purposes. Inside the 15.45 m radius plot was a subplot of 5.64 m radius to sample saplings, a sub- plot of 2.82 m radius for shrubs, a sub-plot with 1 m radius for counting regeneration, and a subplot with 0.56 m radius for sampling leaf litter, herb, grass, and soil. Correction for the slope was applied whenever required.

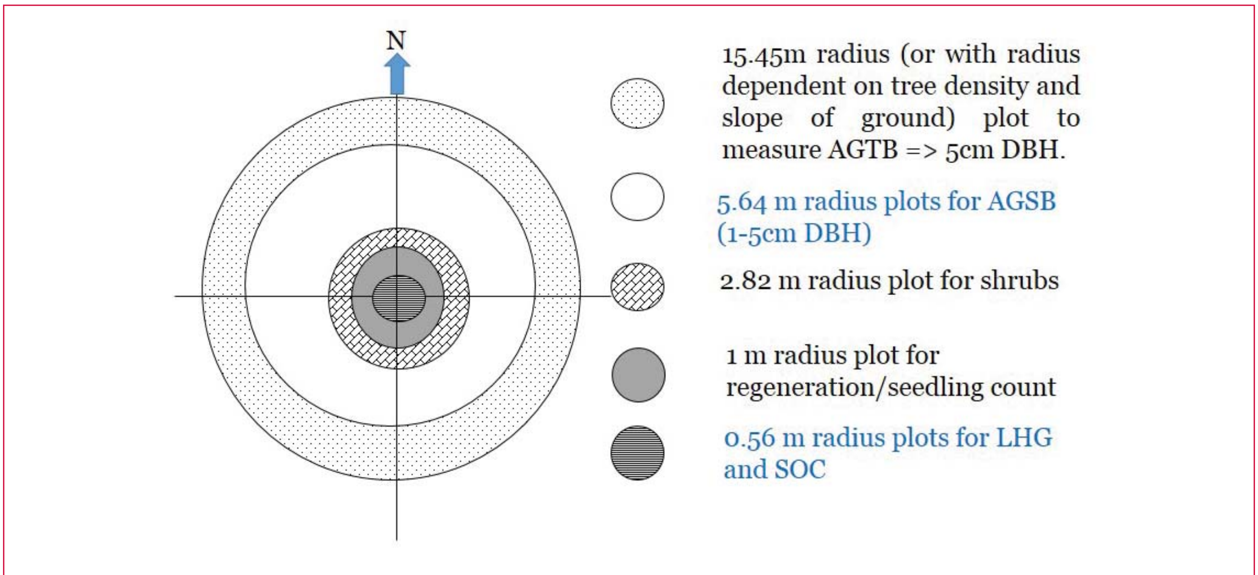


Figure 2: Sample plot design for CHAL forest carbon assessment

3.3.7.2 Forest carbon pools

The forest carbon assessment team monitored three forest carbon pools including above ground (trees, sapling, shrub, herbs, grasses, and litter), below ground (roots), and soil carbon pools (Figure 3). The details of field measurement techniques and methods of estimating forest carbon stock for these different pools are described in succeeding sections.

3.3.7.3 Plot navigation

After uploading the plot coordinates into the Global Positioning System (GPS) device, the teams would use the GPS devices, compasses, and linear tapes to navigate the sample plots in the field as needed. Inaccessible plots or those plots lying in difficult terrains, such as cliffs, roads, rivers, or in cultivated land, were relocated within 50 meters of the plot vicinity using standard forestry practices.

Above ground biomass

- Tree
- Sapling
- Shrubs
- Herbs and Grasses
- Litter

Below ground biomass

Soil organic carbon

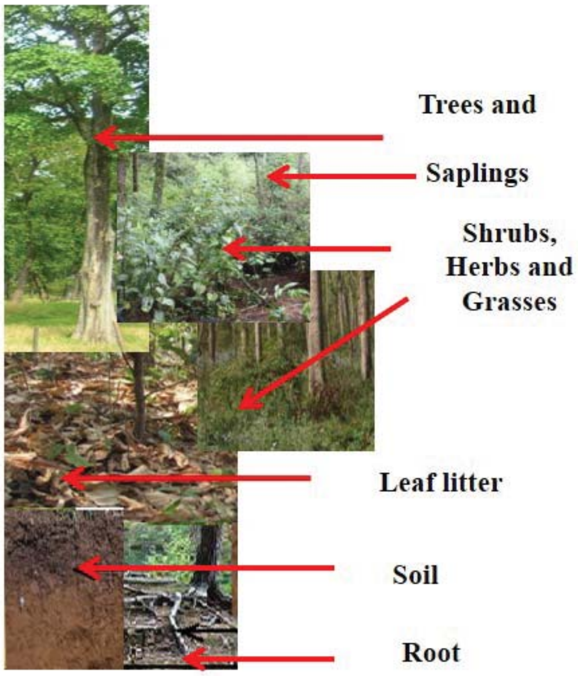


Figure 3: Forest Carbon Pools

3.3.7.4 Centre point marking and referencing

After reaching the center of the plot, the team would mark it with a 1-foot metal pipe inserted in the plot center. The marking in the plot's center is very important for periodic monitoring in the future, as a GPS alone has a margin of error of a few meters when locating the center of the permanent plot. The team recorded the distances and bearings from the plot center to at least 3 or 4 permanent reference points around the center, such as stones, trees, or any other permanent objects. The plot layout sketch recorded the plot center references, their distances, bearings to the center, and other easily recognizable landmarks.

3.3.7.5 Slope correction

Once a team located the center point of the plot, they corrected the slope using a Survey Master Clinometer for slope determination and slope correction factor to convert plot's radius distance into the actual surface length/distance. In addition, the teams were careful to complete the slope correction in each area, since most plots were in hilly terrain.

3.3.7.6 Laying out the permanent plots and measuring carbon pools

3.3.7.6.1 Measurement of above ground biomass

a) Leaf litter, herbs, and grasses (LHG)

At the center of each plot, the team established one circular subplot with a 0.56 m radius to collect and weigh a sample of the leaf litter, twigs, herbs, and grasses. They brought 100 gm of evenly mixed sub-samples to the laboratory to determine the moisture content, from which they calculated the total dry mass. Likewise, they collected herbs and grasses (all non-woody herbaceous plants) within the plots by clipping all the vegetation down to the ground level, placed the sample in a weighing bag, weighed the sample, and brought it to the laboratory to determine the oven dry weight of the biomass.

b) Measurement of shrub

Next, the team established nested a concentric circular plot with a radius of 2.82 m to collect and weigh the shrubs. Of the total weight, 500 grams of shrubs were sent to the laboratory to determine the oven dried weight of the shrub biomass. Destructive harvest methods as prescribed by Pearson *et al.* 2005 were used to measure the biomass inside the nested plot.

c) Measurement of regeneration /seedlings

The main objective of measuring regeneration is to examine the status of regeneration and forest health in the particular forest and to contribute to the development of measures for protecting and managing the forest in a sustainable manner. In a circular plot with a 1m radius, the team would count the regeneration within that plot. Regeneration consists of those seedlings with a height of less than 1m.

d) Measurement of saplings

Saplings have a height of more than one meter and DBH less than 5 cm. The saplings were counted, measured in nested plots with a 5.64 m radius. The team would measure the first sapling to the north of the center of the plot and gradually record other saplings in a clockwise direction. They measured the diameter of each sapling at exactly 1.3 m (breast height) from ground level and recorded it in the given format.

e) Measurement of trees

The study regarded all trees having a DBH equal to or greater than 5 cm as trees for estimating the above ground tree biomass. The survey team counted and measured trees within the nested plot of 750 square meters with a radius of 15.45 m. They measured tree DBH was using diameter tape. They measured tree height using Vertex IV and a transponder. The team followed the standard principles of tree diameter and height measurement to collect height and diameter variables accurately and precisely. Similarly, the diameter and height of irregular trees were measured according to the principles shown in Figure 4. The survey team considered and counted a forked tree as two trees if the fork was <1.3 meters from ground level (DBH) and as a single tree if forking was >1.3 m above the ground.

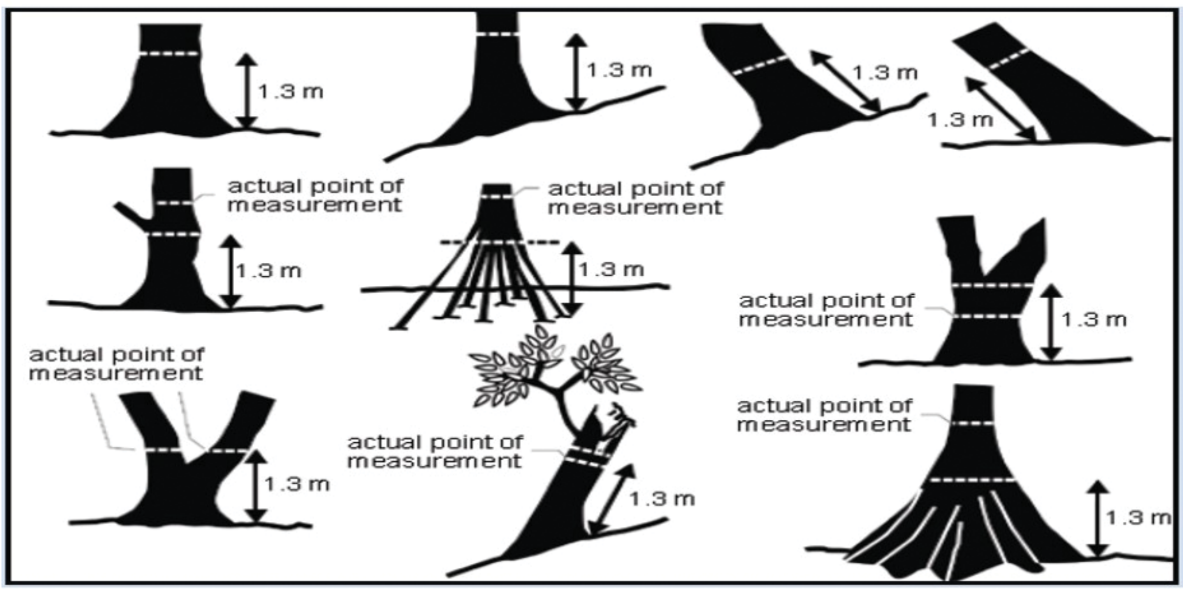


Figure 4: Standard forestry practices while measuring tree diameter at breast height

The team measured individual trees with DBH equal or greater than 5 cm using a diameter tape. In cases of deformed trunks at breast height, the diameter was measured at the nearest (above or below the breast height) well-formed point of the stem. Each tree measured was marked with temporary signs to prevent accidental double counting.

Clinometers and highly sensitive hypsometers, Vertex IV and Transponder T3, were used to measure the height of trees. The survey team was careful measuring the height of leaning trees with the use of Vertex IV because a transponder attached to a tree bole on a leaning tree could result in a biased estimate of tree height unless the lean is at exactly 90° to the observer. The team recorded each tree individually with its species name. Trees on the edge of the plot were included if they have > 50% of their basal area within the plot. They were excluded if > 50% of the basal area was outside the plot. Trees overhanging the plot were excluded, but trees with their trunk inside the sampling plot and branches outside were included.

3.3.7.6.2 Measurement of soil carbon

In accordance with the IPCC (2006) guidelines, the team took soil samples at the center point of each plot and a composite soil sample in separate plastic bags to the National Agriculture Research Council (NARC) laboratory for further analysis. They took sampled soil from three soil cores at each soil layer at 0-10 cm, 10-20cm, and 20-30 cm depth. They carefully wrapped each sample to send it to the laboratory to analyze soil bulk density. As well, the team took a composite soil sample of 100 gram from each permanent plot by mixing all three layers to determine soil organic carbon.

3.3.8 Data compilation, entry, and analysis

After field measurement, the survey teams indexed and entered all the data sheets into the MS-Access software to develop a database, which was exported to Excel and R-program to analyze and produce the required tables and graphs. The above ground biomass (herbs, litter, and grasses, sapling, shrubs, and trees), below ground biomass, and soil carbon were analyzed using equations as in Subedi *et. al* 2010. Finally, the study team summed up all the pools to get the total biomass in each stratum and per hectare of forest. The biomass was converted into carbon using the fraction of 0.47 given by IPCC (2006) and into carbon dioxide using the ratio of 3.67 given by Pearson *et. al* 2007. The detailed equations and formulae applied during the analysis are shown in the following section.

3.3.8.1 Data analysis of above ground biomass

a) Shrubs, Leaf litter, herbs, and grasses (ShLHG)

For shrubs, leaf litter, herbs, and grasses, the amount of biomass per unit area was calculated by using the following equation (iii):

$$S_hLHG = \frac{^{w}\text{field}}{A} \cdot \frac{^{w}\text{subsample,dry}}{^{w}\text{subsample,wet}} \times 10000 \text{ .... Eq. (ii)}$$

Where,

S_h LHG	=	biomass of shrubs, leaf litter, herb, and grass [t ha^{-1}];
W_{field}	=	weight of the fresh field sample of shrubs, leaf litter, herb, and grass, destructively sampled within an area of size A [gm];
A	=	size of the area in which leaf litter, herb, and grass were collected [m^2];
$W_{Subsample,dry}$	=	weight of the oven-dry sub-sample of shrubs, leaf litter, herb, and grass sent to the laboratory to determine moisture content [gm]; and
$W_{Subsample,wet}$	=	weight of the fresh sub-sample of shrubs, leaf litter, herb, and grass sent to the laboratory to determine moisture content [gm].

b) Sapling biomass

To determine the biomass of saplings (<5cm DBH), the team used national allometric biomass equations developed by the Department of Forest and Department of Forest Research and Survey Nepal 2000. For tree species, equations were applied according to the given associations of species and forest type.

The regression model below [Eq. iv)] was applied to calculate sapling biomass.

log(AGSB)= a + b log(D) ....Eq.(iV)

where,

Log	=	natural log (dimensionless)
AGSB	=	aboveground sapling biomass (kg)
A	=	intercept of allometric relationship for saplings (dimensionless)
B	=	slope allometric relationship for saplings (dimensionless) and
D	=	diameter at breast height (at 1.3m above ground) (cm)

The Department of Forest Research and Survey (DFRS) and the Department of Forest Tree Improvement and Silviculture Component (TISC), Nepal (Tamrakar 2000) (Annex 10) developed the variables and regressions for slope and intercept for all saplings.

c) Tree biomass (Above ground)

Depending on the ecological condition of the forest, the above ground biomass calculations were based on the appropriate equation Eq (vi) in the forest carbon measurement guidelines as suggested by Chave (2005, p. 93) for moist forest stands.

$AGTB = 0.0509^{*}\ pD^{2}H$ ....Eq.(Vi)

where,

AGTB	=	aboveground tree biomass (kg)
P	=	wood specific gravity (kg m^{-3});
D	=	tree diameter at breast height (DBH) [cm]; and
H	=	tree height (m)

Specific wood gravity (*P*), as stated in the Master Plan for Forestry Sector (MFSC), was used in the calculation. For the tree species without a predetermined wood specific gravity, a general value was used according to the associated forest types (MSFC 1989).

d) Below ground tree biomass

Below ground biomass is usually the biomass of roots. It was estimated using the default root-to-shoot ratio value. According to Geider *et al.* 2001, measurements of root biomass are highly uncertain, so the lack of empirical values for this type of biomass has been a major weakness in ecosystem models for decades. In this study, below ground biomass was calculated with the root-to-shoot ratio value of 1:5 as suggested by MacDicken (1997). This means that the below ground biomass is about 20% of above ground tree biomass.

3.3.8.2 Data analysis for soil carbon

The carbon stock of soil organic carbon was calculated by Eq. (vii) (Pearson *et al.* 2007)

SOC = p x d x %C ....Eq. (vii)

Where,

SOC = Soil organic carbon stock per unit area [t ha^{-1}];
P = Soil bulk density [gcm^{-3}];
d = The total depth where the sample was taken [cm]; and
%C = Carbon concentration [%].

3.3.8.3 Total forest carbon stock calculation

The total forest biomass of each pool was converted into forest carbon stock by multiplying by the default carbon fraction of 0.47 as the IPCC (2006) recommended. Then, the equation viii, was used to determine the total forest carbon stock by summing all carbon pools calculated to have forest carbon stock (in ton) per unit area.

C(LU) = C(AGTB) + C(SB) + C(ShLHG) + C(BB) + SOC ....Eq. (viii)

Where,

TC (LU) = carbon stock for a land use category [tC ha^{-1}];
C (AGTB) = carbon stock in aboveground tree biomass [tC ha^{-1}];
C (SB) = carbon in sapling biomass [tC ha^{-1}];
C (ShLHG) = carbon in shrubs, leaf litter, herbs and grass [tC ha^{-1}];
C (BB) = carbon in belowground biomass [tC ha^{-1}];
SOC = soil organic carbon [tC ha^{-1}];

The carbon stock was converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.* 2007).

3.4 Quality Assurance and Quality Control

The adequate quality assurance of an inventory requires both internal and external control procedures. Internal control activities are intended to ensure accuracy, documentation, and transparency of the inventory operations. The agency responsible for compiling the inventory in each country implements this control during the compilation of the data and calculations. This agency should check the availability of actual data, and its correctness, consistency, and completeness. It should also document the origin of data and the specific assumptions adopted. The implementation of an approved standardized procedure for emission calculations may improve the accuracy of an inventory and the internal control.

In addition, inventory activities should be implemented cooperatively, so that the different national experts involved in the work can provide the specific skills required to make decisions and assumptions. The inventory report should describe the specific context of each emission source systematically. The inventory results should be presented publicly to stimulate the feedback from national experts. The external control is collected through relevant external reviews, designed to minimize the risk of potential errors and bias. The way in which the internal QA (quality assurance) and QC (quality control) are conducted determines the potential conclusions of the reviews for external control.

The team carried out provisions for QA and QC during the whole study period to ensure that the reported carbon stocks and credits are reliable and meet minimum measurement standards. It applied QA/QC provisions at the following stages: (1) collecting reliable field measurements; (2) verifying laboratory procedures; (3) verifying data entry and analysis techniques; and (4) data maintenance and archiving.

3.4.1 QA/QC for field measurements

Rigorous Standard Operating Procedures (SOP) were developed and followed during the fieldwork. The SOP ensures that measurements done by different teams or at different times are consistent and comparable. All the forest technicians and local resource persons involved in the carbon assessment had extensive training in all aspects of field data collection and analyzes to ensure that they collected accurate data. The team had 10% of the plots re-measured independently to compare this data with the original data so that all errors could be corrected and recorded.

3.4.2 QA/QC for laboratory measurements

The laboratory staff prepared Standard Operations Procedures for laboratory measurements and for each part of the analysis. About (5%) of the dry weight of herb, litter, and shrub samples were re-weighed to determine an error estimate and correct errors.

3.4.3 QA/QC for data entry

Field measurements were written down on the field data sheets and were entered manually into spreadsheets thereafter Data entry into spreadsheets is often a significant source of error. Ongoing communication between all personnel involved in measuring and analyzing data is critical for resolving apparent anomalies before final analysis of the monitoring data is completed.

The team paid special attention to units used in the field by using a standard forestry measurement system for all tree DBH, height, and sample weights calculations and measurements. All measurements contained in spreadsheets were clearly indicated. To reduce errors, forest technicians did spot checks of the entered data. In addition, checking each value within an expected range identified any outlier trees.

Veller Tree

Chapter 4

Results and Discussions

This chapter presents a description of the socio-economic conditions, geospatial analysis, and forest carbon stock in CHAL.

4.1 Socio-Economic Baseline

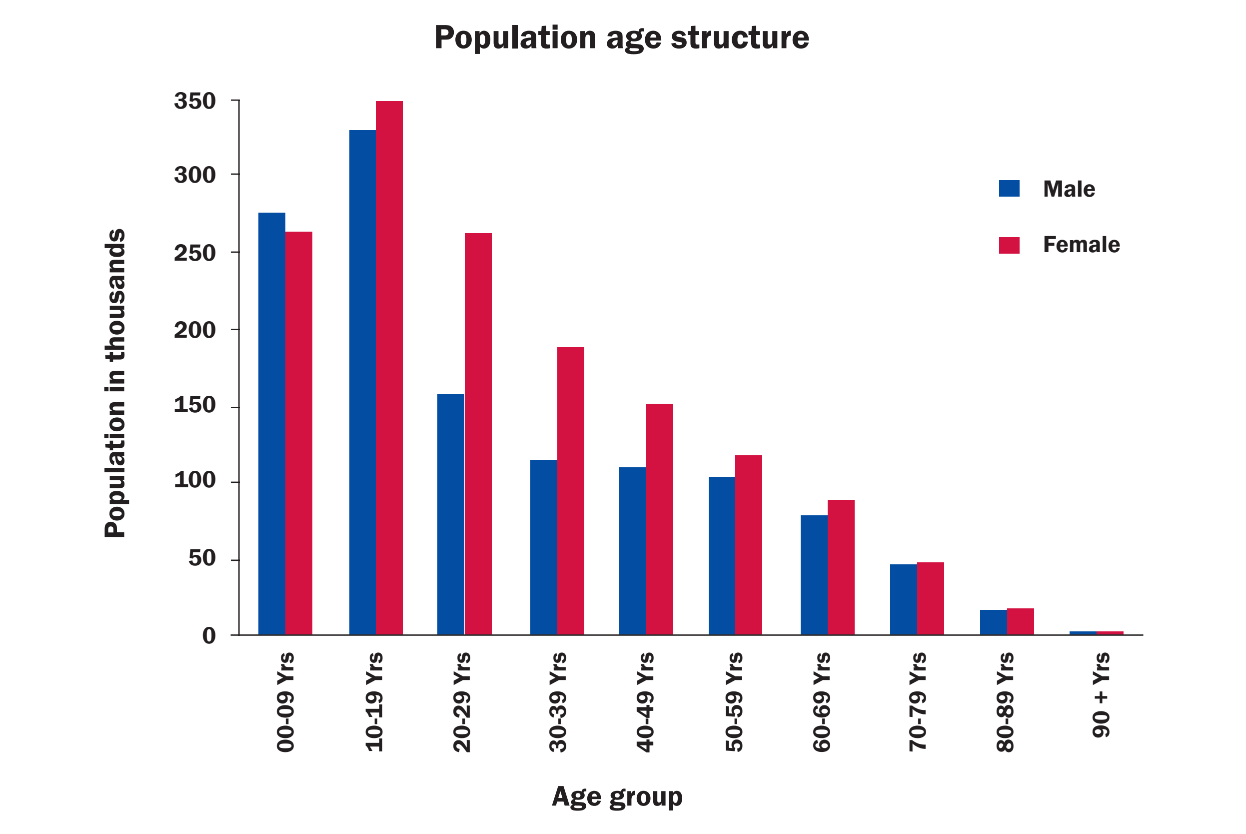
4.1.1 Population

According to the census report of 2011, the studied project districts of CHAL had 649,496 households with a total population of 2,708,380, which was 45% male and 55% female. The male to female ratio was 0.82:1. Two mountain districts -- Manang and Mustang -- have the lowest number of households and populations. The CHAL has an average household size of 3.86, which is less than the national average of 4.88. Details of the population, household size, and household density of the studied districts are presented in Table 8.

Table 8: Population distribution in the studied districts

Districts	Population			Household (HH)	Average HH size	Density (No HH/Sq. Km)
	Male	Female	Total			
Dhading	157,834	178,233	336,067	73,842	4.55	174
Gorkha	121,041	150,020	271,061	66,458	4.08	75
Lamjung	75,913	91,811	167,724	42,048	3.99	99
Tanahu	143,410	179,878	323,288	78,286	4.13	209
Syangja	125,833	163,315	289,148	68,856	4.2	248
Kaski	236,385	255,713	492,098	125,459	3.92	244
Manang	3,661	2,877	6,538	1,448	4.42	3
Mustang	7,093	6,359	13,452	3,305	4.01	4
Myagdi	51,395	62,246	113,641	27,727	4.09	49
Parbat	65,301	81,289	146,590	35,698	4.1	297
Baglung	117,997	150,616	268,613	61,482	4.37	151
Gulmi	120,995	159,165	280,160	64,887	4.32	244
Total	**1,226,858**	**1,481,522**	**2,708,380**	**649,496**	**3.86**	**138.23**

Based on this 2011 census report, 66 % of the total population above 5 years of age is literate. The male literacy rate is notably higher (80%) than female literacy rate (65%). The Figure 5 shows that largest age group in CHAL is ‘10-19 years’ followed by ‘below 9 years’ and ‘20-29 years.’ All age groups, except ‘below 9 years’, have more females, especially the age group ‘20-29 years’, which has the highest female population. The male-female difference decreases as the age increases. This trend could be due to the outmigration of young men for foreign employment.

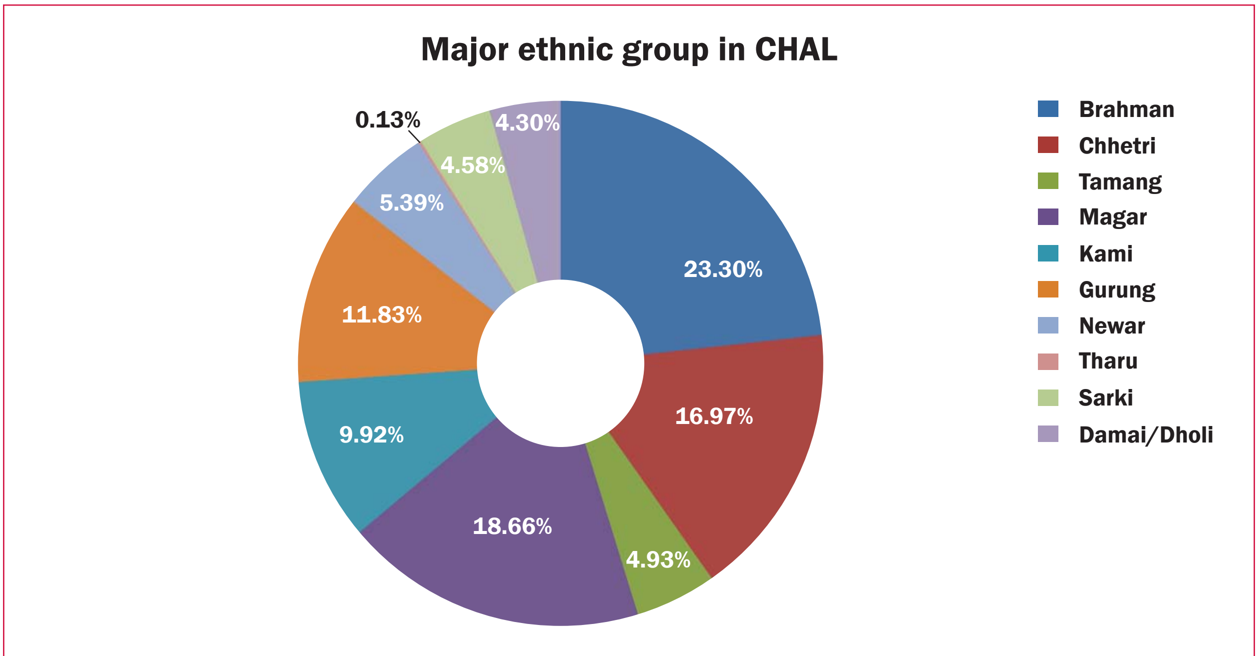


Source: CBS, 2011

Figure 5: Population age structure in CHAL

4.1.2 Caste/ethnicity and religion

The census report states that Hinduism is the dominant religion (83%) followed by Buddhism (13%), Christianity (2%), and Islam (1%) in CHAL. Major caste and ethnic groups in CHAL are Magar, Chhetri, Gurung, Brahmin, and Kami. Other groups with small populations in CHAL are Newar, Tamang, Tharu, Sarki, and Damai/Doli. The CHAL is rich in linguistic diversity with more than 50 different languages spoken.



Source: CBS, 2011

Figure 6: Distribution of ethnic groups in CHAL

4.1.3 Landholdings

The majority of households in the studied districts have landholding of less than one ha, and only 3% of households have landholding of more than two ha. This shows that ownership of the land in CHAL is highly fragmented. All the districts have landless households except for Dhading, Gorkha, and Manang. Syangja has the highest number of landless households. The status of landholdings in the studied districts is shown in Table 9.

Table 9: Percentage of household possessing land in 12 CHAL districts

District	Landless	Percentage of Household holding land (Ha)				
		< 0.1	0.1 to 0.5	0.5 to 1	1 to 2	> 2
Dhading	0	3.84	43.96	36.73	14.05	1.49
Gorkha	0	3.82	44.1	36.64	13.68	1.76
Lamjung	0.37	4.16	45.18	35.92	13.18	1.55
Tanahu	0.89	4.31	39.8	29.97	19.8	5.2
Syangja	3.7	51	33.3	13.3	2.3	0.1
Kaski	0.91	13.76	52.41	22.93	9.3	0.67
Manang	0	13.13	30.88	27.41	22.93	5.65
Mustang	0.19	7.06	58.78	26.57	6.61	0.97
Myagdi	0.14	4.89	49.1	27.72	14.48	3.79
Parbat	0.25	8.22	53.72	27.65	8.77	1.64
Baglung	0.18	4.92	48.08	26.25	14.84	5.76
Gulmi	NA	NA	NA	NA	NA	NA

Source: District Profile 2007-2009

4.1.4 Livelihood strategy

According to the district profiles of the studied districts, 50-80% of the population in CHAL depends on agriculture for their living, mostly traditional farming and livestock rearing. As most households have a landholding of less than one hectare, the agriculture production is not sufficient for food security. Hence, foreign employment has become another important livelihood strategy of the people in CHAL.

In most middle mountain districts, a conventional tillage rice-fallow system is common. The main cereal crops grown are paddy, maize, wheat, millet, barley, and buckwheat. Improved varieties of crops are grown throughout the region.

The production of major crops, such as rice, maize, and wheat is relatively low in CHAL relative to the national average production (WWF Nepal 2012). The productivity of food grain in the selected districts revealed that the productivity ranges from 2-2.5 ton/ha. Similarly, the productivity of legumes and oil-bearing crops (mainly mustard) is low, about 1 ton/ha. The productivity of vegetables, cash crops, potatoes, and fruits is higher, as much as 10 ton/ha. The productivity of various crops in the studied districts is shown in Table 10.

Table 10 : Productivity of various crops in studied districts

District	Productivity (Ton/ha.)					
	Food grain	Legumes	Vegetable/ Cash crop	Oil	Potato	Fruits
Dhading	1.70	-	-	-	0.79	-
Gorkha	2.05	0.95	9.23	1.00	11.55	6.36
Lamjung	2.32	0.70	8.54	0.89	-	-
Tanahu	2.51	0.83	8.00	0.74	8.12	9.69
Syangja	-	-	-	-	-	-
Kaski	2.34	0.77	10.12	0.73	10.30	5.12
Manang	-	-	-	-	10.20	-
Mustang	1.95	1.30	13.31	1.45	12.50	10.78
Myagdi	2.40	1.00	11.11	0.84	15.00	4.26
Parbat	-	-	-	-	-	-
Baglung	2.12	1.03	13.30	1.10	8.29	3.99
Gulmi	1.89	-	13.4	0.93	8.3	-

Note: Food grain includes paddy, maize, wheat, millet, barley; Cash crop includes mainly ginger, turmeric, onion and garlic, coffee, sugarcane

Source: District Profile 2007-2009

Raising livestock and poultry are very common livelihoods practices in CHAL. Although raising poultry has been commercialized, farming other livestock on a commercial scale is just beginning in CHAL. Based on traditional knowledge, the farming communities in CHAL have developed an integrated farming system to fulfill their household needs by combining trees, crops, and livestock in their farming practices. The main livestock in the region is cattle, buffalo, goat, sheep, and pig. In mountainous regions, such as Manang and Mustang, people rear mountain cow and yaks for both food and transportation. Similarly, horse and mule rearing is common in mountainous regions, especially for transportation. Chicken and ducks are reared in CHAL for meat and eggs.

4.1.5 Energy consumption

The sources of energy for cooking in CHAL are fuelwood, LPG, Biogas, kerosene, electricity, and animal dung cake. Fuelwood is the most common source of energy used by 72.4 % of the households. LPG is the second major source of fuel, used mainly for cooking. The other common sources of energy are Biogas, kerosene, and electricity. Sources of household energy are shown in Table 11.

Table 11: Sources of household energy

Fuel sources	Fuel wood	LPG	Biogas	Kerosene	Electricity	Cowdung	Others	Not stated
Household (%)	72.4	22.5	3.8	0.6	0.1	0.2	0.1	0.4

The study shows that a household annually consumes an average of 0.593 metric tons of fuelwood. This data shows that the 12 districts of CHAL consume an annual total of 278,849 metric tons of fuelwood. Despite fuelwood being the main energy source for cooking in CHAL, its consumption is significantly low in districts with more urban areas, such as Kaski, where more LP gas is used. Manang district depends almost entirely on fuelwood for cooking and Mustang depends on cow dung. Biogas is popular in the midhills of CHAL. There is negligible use of electricity for cooking and heating in CHAL (Figure 7).

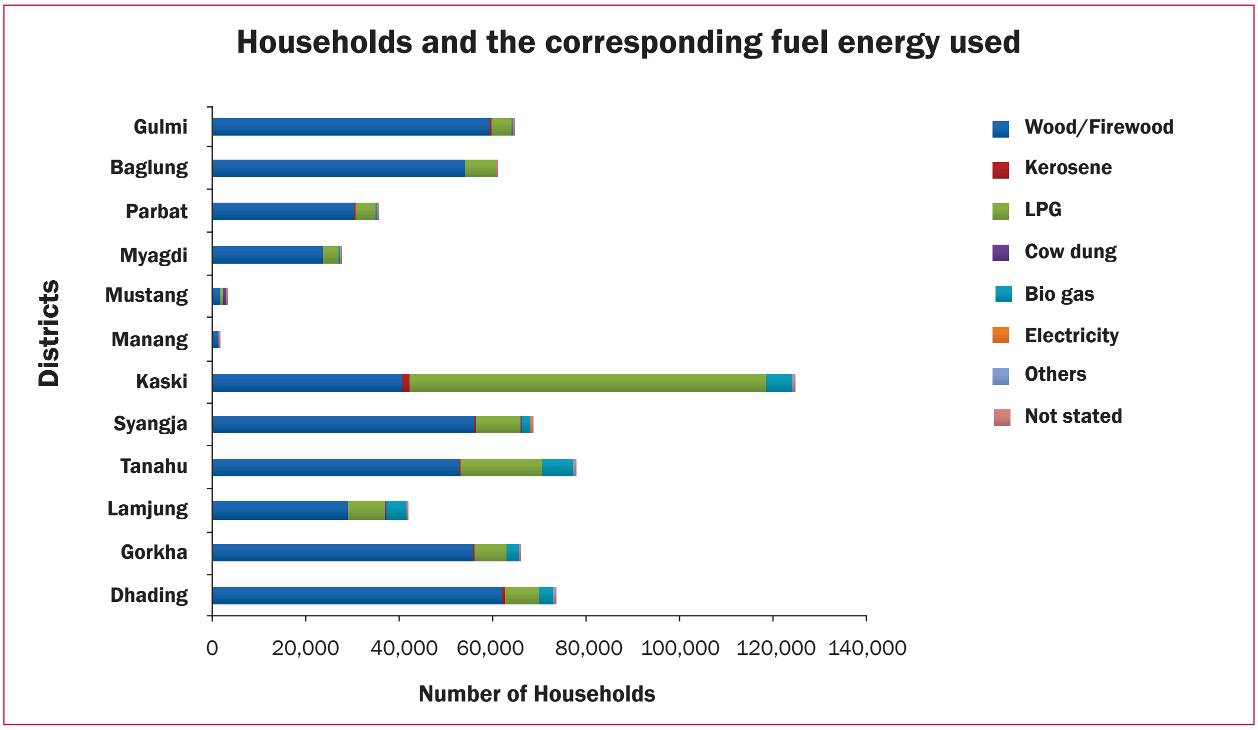


Figure 7: Source of energy in the studied districts

4.2 Forest Cover Baseline

4.2.1 Strata wise forest cover

The CHAL covers 21.64 % (31,854.40 km^2) of the total geographical area of Nepal, and 41.39 % (13,187.41 km^2) of CHAL is forest and shrub area. This study covers only 7,448.66 km^2 of forest area in the selected 12 districts. Table 12 shows the forest area strata-wise in the studied districts.

Table 12: Strata wise forest area in the studied districts

CHAL district area and strata wise area (km^2)														
Forest Strata	Baglung	Dhading	Gorkha	Gulmi	Kaski	Lamjung	Manang	Mustang	Myagdi	Parbat	Syangja	Tanahu	Total Area	Area in %
SB	169.31	213.29	345.76	204.52	239.83	269.99	7.46	3.25	68.18	80.22	151.48	289.92	2043.21	27.4
DB	109.65	444.44	161.46	226.03	159.15	102.63	3.29	3.16	18.50	61.21	252.70	541.78	2083.99	28.0
DN	468.72	138.33	236.12	21.43	194.31	243.82	21.31	13.57	336.34	48.08	10.76	0.50	1733.28	23.3
SN	214.25	141.34	202.04	1.29	304.31	230.45	71.56	51.71	333.33	35.50	2.37	0.03	1588.17	21.3
Total	**961.93**	**937.3**	**945.3**	**453.2**	**897.6**	**846.8**	**103.6**	**71.7**	**756.3**	**225.0**	**417.3**	**832.2**	**7448.6**	**100**

4.2.2 Forest cover change

The study produced land cover statistics and a land cover map showing the LCCS-based 12 classes (Table 13). The overall accuracy of the classification was estimated at 85.13% with producers accuracy at 81% and user accuracy at 82%. Overall, the study obtained a 0.8228 kappa statistics value, indicating a high level of accuracy. The classification accuracy for needle-leaf open forests was relatively low as it was difficult to distinguish between open and dense forests, regardless of the forest type class.

Table 13: Summary of accuracy assessment report

Land cover	Reference Total	Classified Total	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
Needle-leaf closed forest	45	46	38	84.44%	82.61%
Needle-leaf open forest	25	23	15	60.00%	65.22%
Broad-leaf closed forest	76	89	71	93.42%	79.78%
Broad-leaf open forest	45	35	27	60.00%	77.14%
Shrubland	21	23	16	76.19%	69.57%
Grassland	33	27	22	66.67%	81.48%
Agriculture area	186	187	174	93.55%	93.05%
Barren area	49	49	45	91.84%	91.84%
Lakes	25	15	15	60.00%	100.00%
Rivers	12	14	11	91.67%	78.57%
Snow/glaciers	22	30	22	100.00%	73.33%
Built-up area	26	27	25	96.15%	92.59%
Total	**565**	**565**	**481**		

Land change (LC) detection using remotely sensed data attempts to identify natural and human impacts on earth (Qamer *et al.* 2012). To identify changes, the team cross-tabulated a change matrix with eight classes at two different points for 1978-1990, 1990–2000, 2000–2010, and 1978-2010. In the change matrix, diagonal values showed the stability of the LC class, while the commission and omission values indicated a shift in area or percentage between classes (Olofsson *et al.* 2013). Using the change matrix in the defined project area, 'gross change, forest to non-forest', 'gross change, non-forest to forest', and 'net change' were examined for each decade interval to analyze the forest situation (Table 14). These were used to generate a map of the spatial trend in forest cover from 1978 to 2010, which could be linked with ancillary information to help advance the understanding of recent changes and to support forest resource management (Annex 5 and 6).

The study identified changes in deforestation or degradation and forest regeneration and re-growth between 1978 and 2010 visually by using medium resolution (Landsat) images (Annex 7).

Table 14: Change in forest area (1978-2010)

Land use	Area (km^2)			
	1978–1990	1990-2000	2000-2010	1978-2010
Gross change, forest to non-forest	786.23	716.10	675.22	1177.55
Gross change, non-forest to forest	559.17	601.82	732.64	893.63
Net change	-227.07	-114.28	57.42	-283.93

4.2.3 Land cover simulation 2020

The change analysis panel provided a rapid quantitative assessment of change by graphing gains and losses of different land cover categories. Transition potential modeling, which is determining the net change, showed the outcome of adding gains and then subtracting losses from earlier land cover areas (Ahmed *et al.*, 2013).

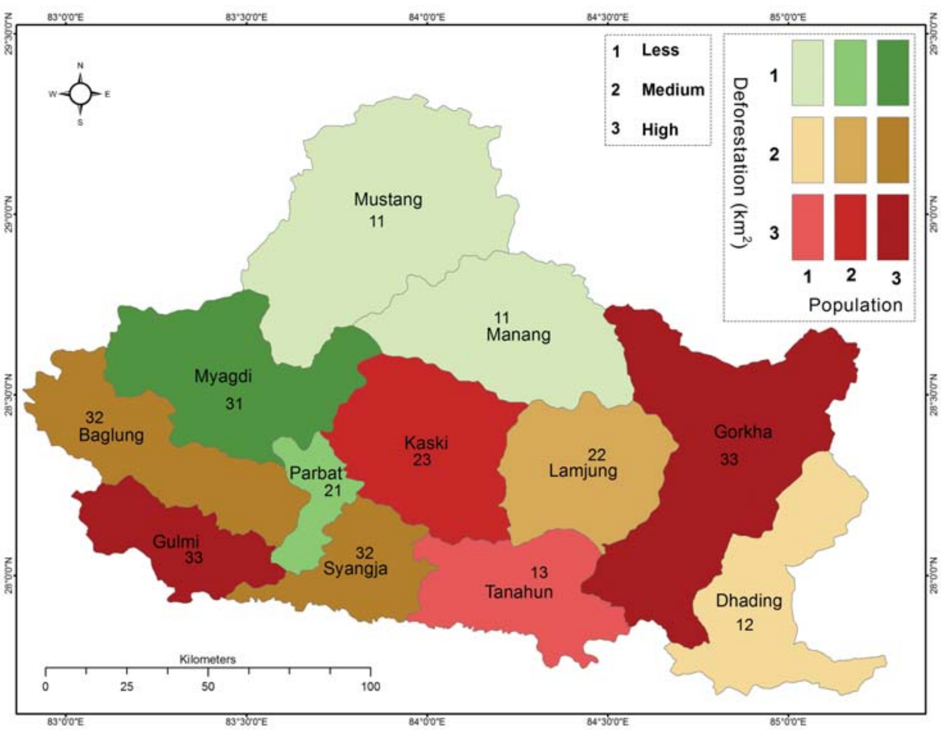
For land cover change analysis and prediction in this study, a land cover image from the year 2000 was compared with a land cover image from 2010 and imported into IDRISI Selva in a raster (IDRISI raster) format. The team reviewed and assessed historical changes between land cover maps of 2000 and 2010 and then used Land Change Modeler (LCM) for empirical modeling of land cover change. They created maps with distances to roads, major urban centers, and slopes given that infrastructure development and slopes are major drivers of deforestation. Landsat 8 (30 m) is already functioning and taking satellite images and has an expected lifetime of 10 years. Thus, in ten years' time, it will be possible to validate simulations based on the LC-20 (Table 15).

Table 15: Change in forested area (2010 to 2020)

Land uses	Area (km^2) 2010–2020
Gross change, forest to non-forest	1039.47
Gross change, non-forest to forest	1219.50
Net change	180.03

4.2.4 Bivariate forest cover analysis

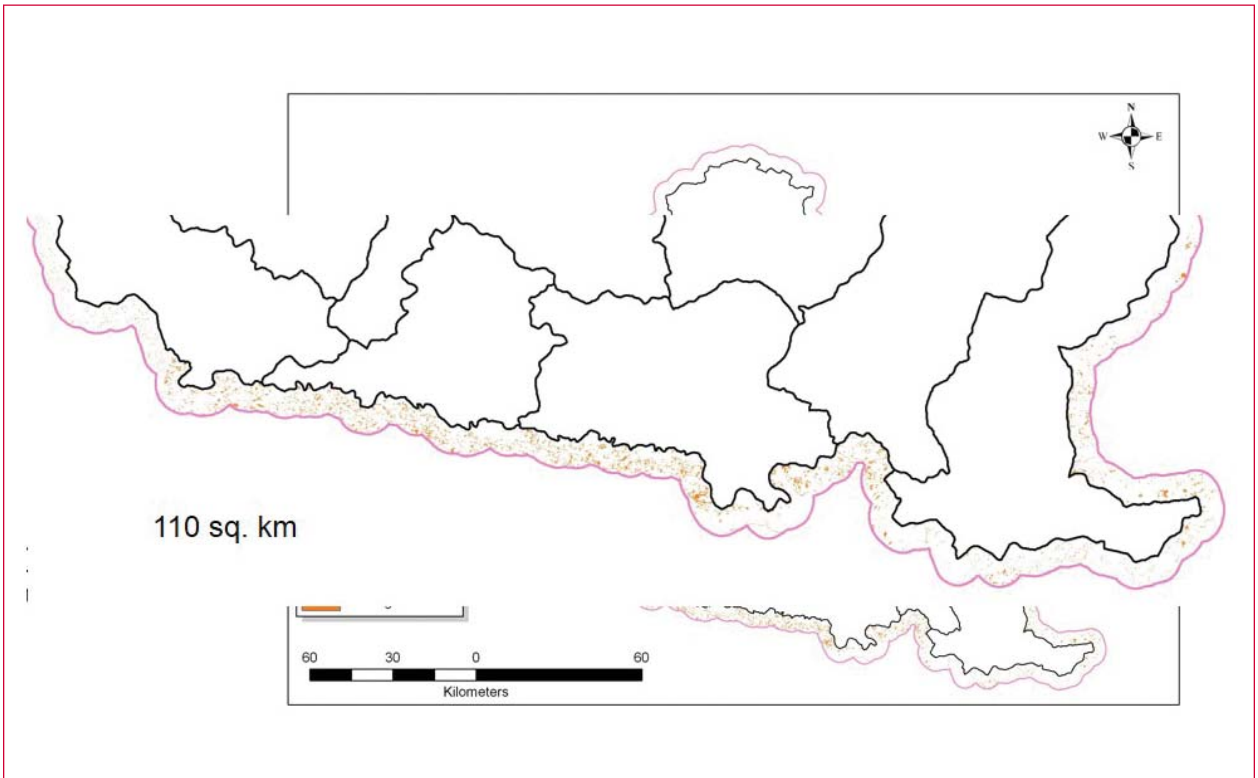
Bivariate analysis is one of the simplest forms of the quantitative (statistical) analysis. It involves the analysis of two variables to determine the empirical relationship between them. It is common to measure how those two variables simultaneously change together in order to see if the variables are related to one another (Nandi and Shakoor 2010). This study developed a bivariate map using the deforestation and population data in the studied 12 CHAL districts. The map developed shows clearly which districts have high, moderate and low populations and deforestation (Map 7). For example, Gorkha and Gulmi have higher deforestation and population, while Mustang and Manang have the lowest variables.



Map 7: Bivariate map based on deforestation and population in the 12 districts

4.2.5 Forest carbon leakages

The total possible leakage area was identified using GIS analysis, by considering the socio-economic status, accessibility of roads, demand and supply of timber and fuelwood, and deforestation rates in the forest. The study estimated the total leakage area in CHAL to be 110 km^2. The possible leakage belt was south, east, and west within 5 km of forest boundaries. The team did not consider areas to the north of CHAL as they lie on the border of Tibet (Map 8).



Map 8: Map showing the possible leakage belt in CHAL

4.2.6 Drivers of deforestation and forest degradations

Deforestation and forest degradation are two important dimensions of environmental change directly related to global warming. They also pose serious threats to biodiversity and the livelihoods of local communities depending on the forests. Deforestation refers to the complete loss of forest cover. Forest degradation refers to the loss of biomass (carbon) and reduced capacity of forests to provide ecosystem services.

Efforts to halt or reverse deforestation trends in Nepal have not yet been successful despite innovative approaches to forest management and the expansion of forestry administration. Reports indicate that Nepal's forest area has decreased continuously since 1978 (38.1%) to 37.4% in 1985/86 to 29% in 2001 (Table 16). Recent estimates show that Nepal's forest area decreased at an annual rate of 2.7% and that shrublands increased at an annual rate of 12.7% from 1991 to 2001 (WWF 2012).

Table 16: Land use change in the country since 1978-2001

Type of Land	1978/79	1985/86	2001
Cultivated land	20.1	20.7	21.0
Non cultivated land	6.7	6.8	7.0
Forest	38.1	37.4	29.0
Shrub land	4.7	4.8	10.6
Grass land	11.9	11.8	12.0
Other land	18.5	18.5	17.8
Water/Lake	-	-	2.6
Total	**100%**	**100%**	**100%**

Source: Environmental statistics of Nepal, 2011

WWF Nepal (2012) conducted an analysis of land use change in CHAL for the period 1990-2010. It showed that the forest area in CHAL remained more or less stable from 1990-2010. However, the area of grasslands substantially decreased while the agricultural area slightly increased. The changes in the area covered by alpine meadows and shrublands did not show a clear trend.

The forest areas in CHAL remained unchanged, but in many parts of the Siwalik lowlands, there were reports of substantial losses in forest area due to infrastructure development, resettlement, urban expansion, and agricultural expansion. Similarly, the unregulated construction of rural roads in the middle mountains has caused forest loss in many locations, which has undermined the community forestry program's goal of improving forest cover and conditions. Nevertheless, reports indicate an increase in forest cover within protected areas, such as Annapurna and Manaslu conservation areas.

The study identified and prioritized six major indicators of drivers of deforestation (DoD) and forest degradation based on the field assessment, the driver's occurrence on the plots, and the various parameters recorded in 300 permanent sample plots in the CHAL. The drivers include forest fires, lopping for fodder collection, grazing, firewood collection, timber extraction, and soil erosion.

In CHAL, signs of deforestation and forest degradation have been visible for many years due to the socio-economic conditions and the dependence of local people on the forest resources. This study found that firewood collection was a major driver among the six categories of DoD followed by grazing, lopping, timber extraction, soil erosion and landslides, and forest fire (Table 17).

Table 17: Major drivers of deforestation and forest degradation in CHAL

S.N.	Category of DoD in CHAL	Percentage of occurrence (in priority order)
1	Firewood collection	66.7
2	Uncontrolled grazing	50.3
3	Lopping of forest trees	47.7
4	Illegal timber extraction	38.3
5	Soil erosion and landslides	20.3
6	Forest fire	10

4.3 Forest Carbon Baseline

For biomass and carbon stock estimation, the study measured 17,053 trees in 300 permanent sampling plots. Of the total trees measured, nine identified as possible outliers were excluded in the analysis (Annex 11).

4.3.1 Dominant tree species

The forest carbon assessment recorded 145 tree species in CHAL (Annex 8). Based on their density, frequency and basal area, eight species were the dominant tree species – Sal *(Shorea robusta)*, Chilaune *(Schima wallichii)*, Khote salla *(Pinus roxburghii)*, Katus *(Castanopsis indica)*, Gobre salla *(Pinus wallichiana)*, Utis *(Alnus nepalensis)*, Gurans *(Rhododendron arboretum)*, and Mahuwa *(Engelhardia spicata)* (Figure 8).

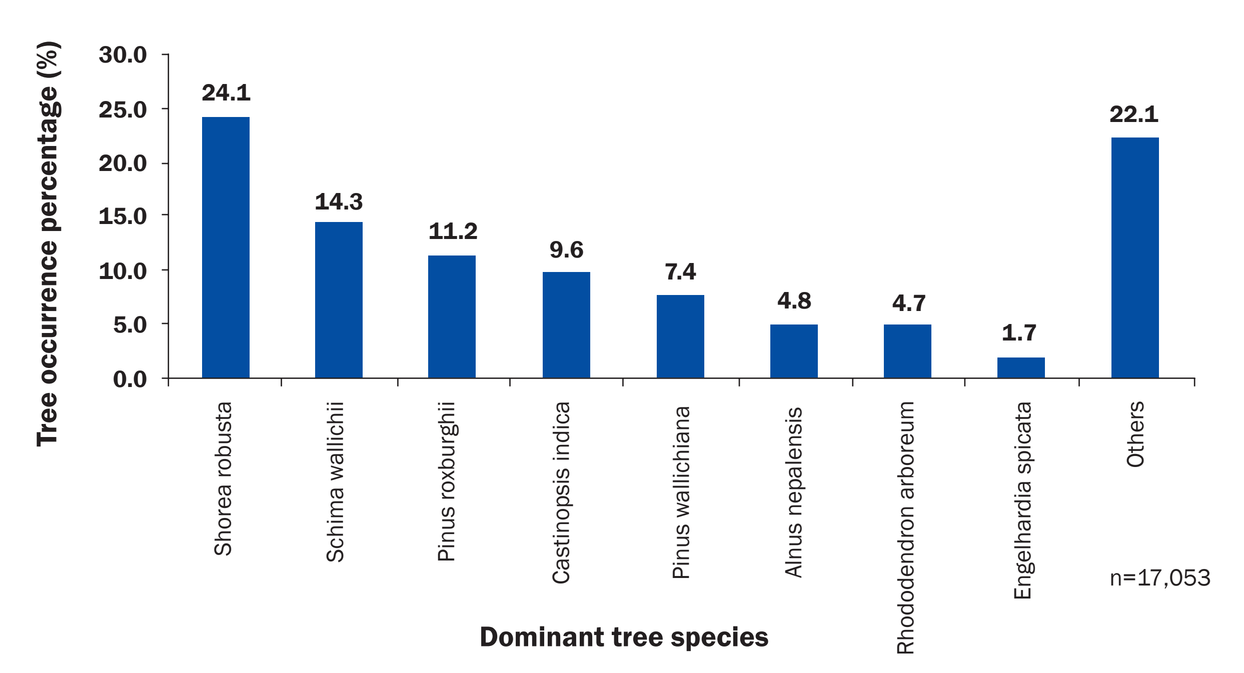


Figure 8: Dominant tree distribution (%) in CHAL

4.3.2 Forest characteristics

The presence of high numbers of seedlings and saplings on the forest floor indicates that the forest is regenerating. A graph plotted with the total number of seedlings, saplings pole, and the trees per hectare in CHAL shows an exponential J-shaped trend, which is an ideal state for a regenerating forest (Figure 9).

4.3.2.1 Number of stems (DBH≥5cm)

The total number of stems (DBH ≥5 cm) in CHAL was 539.06 million. The average number of stems per hectare was 723 (Table 18). The mean value for tree density in this study is comparable with the mean tree density (731 stems/ha) in Churia forests but slightly higher than the tree density (583 stems/ha) in Terai forests of Nepal, as estimated by Forest Resource Assessment Nepal in 2010-2012.

The species wise number of stems in the CHAL shows that *Shorea robusta* was the most dominant species (174 trees /ha), followed by *Rhododendron arboretum* (103 trees /ha). The average DBH of *Pinus wallichiana* was largest (25.2 cm), followed by *Alnus nepalensis* (20.9 cm). The average height of *Pinus wallichiana* at 18.7 m was highest, followed by *Alnus nepalensis* with a height of 16.6 m (Table 19).

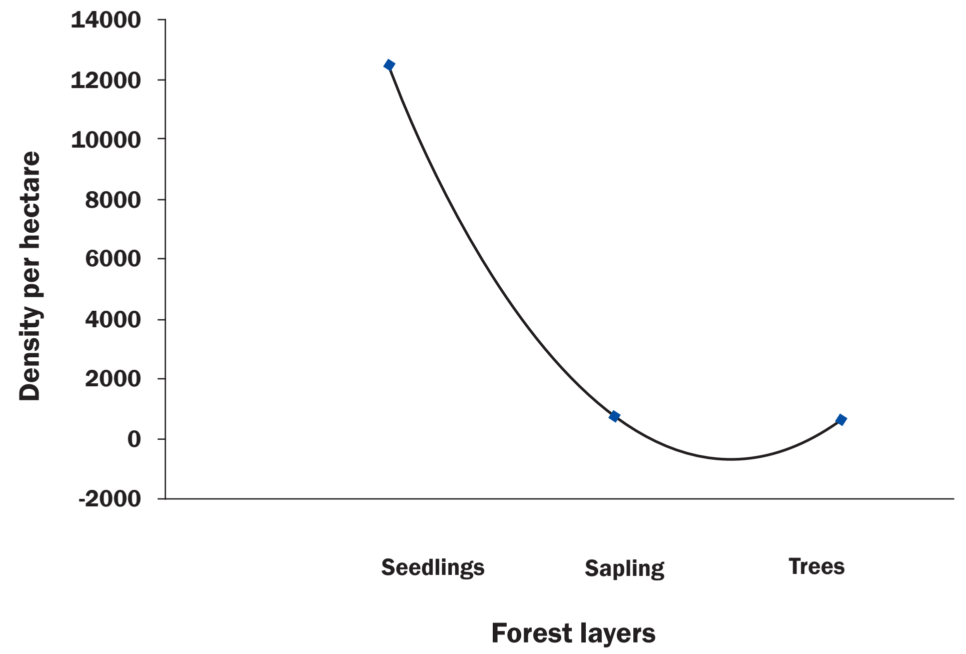


Figure 9: Forest community characteristics

Table 18: Tree stem number by strata and number of trees per plot

Strata	No. of plots	No. of stem/ha	No. of trees /plot
DB	95	1016	76
DN	53	745	56
SB	116	630	47
SN	36	502	38
Total/Average	**300**	**723**	**54**

Table 19: Characteristics of common tree species

S.N.	Scientific name	Average no. of stem per ha	Average DBH (cm)	Average height (m)
1	*Shorea robusta*	174	16.4	12.1
2	*Schima wallichi*	54	17.6	11.0
3	*Pinus roxburghii,*	81	21.3	15.1
4	*Pinus wallichiana*	35	25.2	18.7
5	*Castanopsis indica*	69	14.5	9.7
6	*Alnus nepalensis*	34	20.9	16.6
7	*Rhododendron arboretum*	104	17.1	7.7
8	*Engelhardia spicata*	12	16.0	9.5
	Other species	160	17.1	10.5
	Total	**723**		

The tree density per hectare varied among the eight dominant tree species depending on the elevation, which also determined the natural boundary of their distribution. *Shorea robusta* was the most dominant tree (777 trees/ha), and *Engelhardia spicata* was the least dominant tree species (52 trees/ha) at elevations below 1,000 m.However, in middle hill elevations from 1,000 m to 1,500 m, *Pinus roxburghii* was the most dominant tree (865 trees/ha) *Rhododendron arboretum* was the least dominant (131 trees/ha). In the 1,500-2,000 m elevation range, *Pinus wallichiana* was the most dominant tree (760 trees/ha) species, and *Engelhardia spicata* was the least dominant tree (163 trees/ha). *Pinus wallichiana* was the most dominant species (500 trees/ha) in 2,000-2,500m elevation, and *Castanopsis indica* was the least dominant tree (93 trees/ha). At elevations above 2,500 m, *Pinus wallichiana* was the most dominant species (524 trees/ha) and *Rhododendron arboretum* was the least dominant (274 trees/ha) tree species (Table 20).

Table 20: Dominance of tree species across the altitudinal range

Species	Altitude and trees density per hectare				
	≤1000	1000-1500	1500-2000	2000-2500	>2500
Shorea robusta	775	439	273	0	0
Pinus wallichiana	0	0	760	500	554
Pinus roxburghii	338	865	395	320	0
Rhododendron arboretum	0	131	225	250	274
Castinopsis indica	313	184	242	93	0
Alnus nepalensis	313	323	243	165	0
Schima wallichii	265	253	208	116	0
Engelhardia spicata	52	207	163	0	0
Others	180	200	445	505	360

4.3.2.2 Tree stem distribution based on diameter class

Figure 10 shows the distribution of trees in DBH classes with the most trees (39.80%) between 10 - 20 cm, followed by 32.07% of trees in DBH classes <10 cm and 18.54% in DBH class 20 - 30 cm. Among larger trees, 6.37% were in DBH class 30 – 40 cm, 2.02% had DBH 40 – 50 cm, and 1.20% were >50 cm DBH.

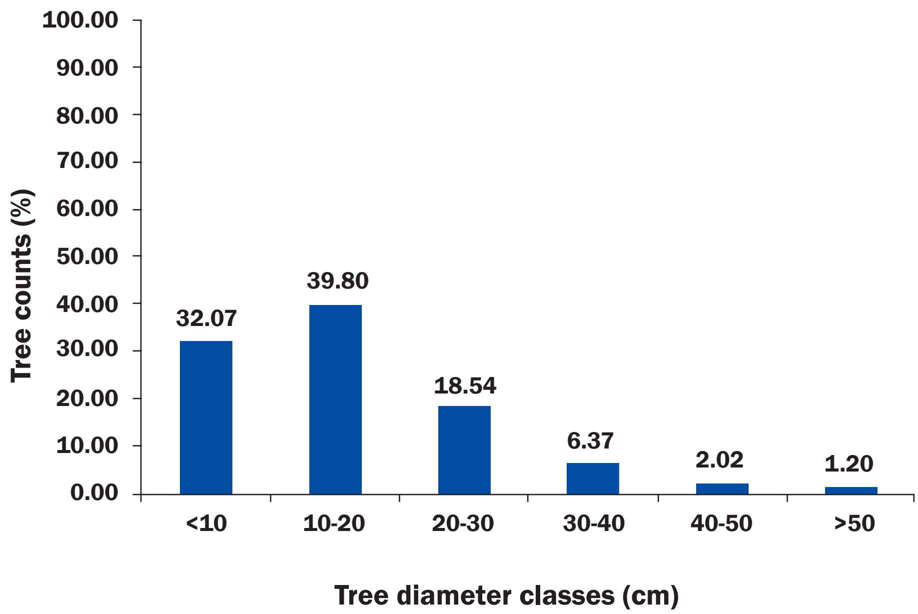


Figure 10: Tree diameter class distribution

The low numbers of trees in the higher DBH class suggest that the forest in CHAL is young, healthy, and regenerating (Figure 11). The distribution of diameter classes of the total individuals counted in the study shows that the diameter class from 10-20 cm has the highest number of individuals and that this number decreases as the DBH increases. However, the class <10 cm has fewer individuals due to the height criteria used to separate trees from saplings. The very young DBH class 10-20 cm has about 328 trees per hectare. Meanwhile the diameter class ≥50 has only nine trees per hectare (Table 21).

Table 21: Major species and DBH class wise number of stems per hectare

S.N.	Scientific Name	DBH Class (cm)					
		5-10	10-20	20-30	30-50	≥50	Total
1	Shorea robusta	50	81	31	11	2	174
2	Rhododendron arboreum	3	13	23	14	1	54
3	Pinus roxburghii	6	35	29	11	0	81
4	Castanopsis indica	9	18	4	3	1	35
5	Schima wallichi	21	38	8	2	0	69
6	Alnus nepalensis	2	16	13	4	0	34
7	Pinus wallichiana	21	54	20	8	1	104
8	Engelhardia spicata	5	4	1	2	0	12
9	Other species	48	69	24	14	4	160
Total		165	328	153	69	9	723

4.3.2.3 Number of seedlings and saplings (DBH ≤ 5 cm)

The natural regeneration of forest in CHAL was good. The number of seedlings (height <1.3m) was 12,490 per hectare, which is slightly lower than that the Chure (19,805 seedlings/hectare) forests of Nepal and less than half of the number in the Terai forest (30,000 seedlings/ha). The number of saplings (height ≥1.3m, and diameter ≤5cm DBH) was 801 per ha, which is almost half of the Terai forest (1600 saplings/ha) and comparable with the Churia (958 saplings/ha) forests. *Shorea robusta* was the dominant species of seedlings (over 18,000/ha) and saplings (over 300/ha) (Table 22).

Table 22: Species composition of seedlings and saplings

S.N.	Scientific Name	Seedlings (No/ ha)	Saplings (No/ha)	Total (No/ha)
1	*Shorea robusta*	4924.89	182.93	5107.72
2	*Schima wallichi*	569.13	13.76	582.79
3	*Pinus roxburghii,*	189.71	6.91	196.22
4	*Pinus wallichiana*	516.01	24.77	540.08
5	*Castanopsis indica*	1244.50	92.72	1337.22
6	*Alnus nepalensis*	265.59	16.92	282.51
7	*Rhododendron arboreum*	1145.85	103.45	1249.3
8	*Engelhardia spicata*	295.95	5.93	301.48
9	Other species	3338.91	353.83	3692.54
	Total	12490.54	801.22	13289.86
	Overall Condition	Good	Fair	Good

4.3.3 Basal area

The total basal area of live trees in CHAL forests was 19.37 million m^2. The average basal area was found to be 26.01 m^2 ha^{-1} (Table 23). The basal area in CHAL was slightly higher than in the Terai (18.38 m^{2}ha^{-1}) and in the Churia (18.77 m^{2}ha^{-1}) as estimated by FRA (2014). Of the four different forest strata, the dense needle-leaf forest strata had the highest basal area (36.49m^2 ha^{-1}) and sparse needle-leaf forests the lowest (18.24m^2 ha^{-1}).

Table 23: Stratum wise basal area (≥5cm DBH)

S.N.	Stratum	Basal area (m2 ha-1)
1	DB	31.03
2	DN	36.49
3	SB	18.26
4	SN	18.24
	Average	**26.01**

The data in Table 24 shows that the per hectare basal area was the highest at 11.81 m^{2}ha^{-1} in the 10-20 cm diameter class, followed by in 5-10 cm diameter class at 5.85m^{2}ha^{-1}. *Shorea robusta* had the highest basal area with 6.27 m^2 ha^{-1} (24%) of the total basal area, followed by other species with 5.74 m^2 ha^{-1} (22%). The lowest basal area was for *Engelhardia spicata* (0.45 m^2 ha^{-1}).

Table 24: Major species and DBH classes wise basal area (≥5 cm dbh)

S.N.	Scientific Name	DBH Class (cm) wise Basal area (m^{2}ha^{-1})					
		5-10	10-20	20-30	30-50	≥50	Total
1	*Shorea robusta*	1.78	2.92	1.11	0.39	0.07	6.27
2	*Schima wallichi*	0.1	0.47	0.84	0.5	0.03	1.94
3	*Pinus roxburghii*	0.2	1.27	1.04	0.39	0.02	2.92
4	*Pinus wallichiana*	0.29	0.66	0.15	0.11	0.03	1.24
5	*Castanopsis indica*	0.77	1.35	0.27	0.08	0.02	2.49
6	*Alnus nepalensis*	0.06	0.57	0.47	0.14	0.01	1.25
7	*Rhododendron arboretum*	0.74	1.92	0.71	0.31	0.04	3.72
8	*Engelhardia spicata*	0.18	0.16	0.04	0.06	0.01	0.45
9	Other species	1.73	2.49	0.88	0.5	0.14	5.74
Total		**5.85**	**328**	**153**	**69**	**9**	**723**

4.3.4 Stem volume

The total stem volume of live trees in the CHAL was 48.18 million m^3. The mean stem volume of live trees was 64.69 m^{3}ha^{-1} (Table 25), which was less than half of that in the Terai (167.42 m^{3}ha^{-1}) and Churia forests (153.99 m^{3}ha^{-1}). This might be due to a higher number of trees with a small diameter class in CHAL forest as compared to Terai and Churia forests.

Table 25: Stem volume (≥5cm DBH) of live trees

S.N.	Stratum	Volume (m^3 ha^{-1})	Total volume (million m^3)
1	DB	60.14	13.48
2	DN	72.72	11.21
3	SB	60.29	13.22
4	SN	65.62	10.27
	Total/Average	**64.69**	**48.18**

Table 26 shows the per hectare stem volume of different species. The stem volume was highest, 29.4 m^3ha^{-1}, in the 10-20 cm diameter class and lowest at 0.88 m^3ha^{-1} in the ≥50 cm diameter class. *Shorea robusta* had the highest, with 24.10% of the total stem volume; *Engelhardia spicata* had the lowest with 1.73% of the total stem volume in the CHAL.

Table 26: Major species and DBH class wise stem volume (≥5cm DBH)

S.N.	Scientific Name	DBH Class (cm) wise stem volume (m^2ha^{-1})					
		5-10	10-20	20-30	30-50	≥50	Total
1	*Shorea robusta*	4.42	7.26	2.77	0.97	0.17	15.59
2	*Schima wallichi*	0.25	1.16	2.1	1.23	0.08	4.82
3	*Pinus roxburghii*	0.51	3.14	2.59	0.98	0.04	7.26
4	*Pinus wallichiana*	0.73	1.65	0.36	0.27	0.07	3.08
5	*Castanopsis indica*	1.91	3.37	0.68	0.19	0.04	6.19
6	*Alnus nepalensis*	0.15	1.42	1.17	0.35	0.02	3.11
7	*Rhododendron arboretum*	1.85	4.79	1.76	0.76	0.09	9.25
8	*Engelhardia spicata*	0.44	0.42	0.1	0.14	0.02	1.12
9	Other species	4.31	6.19	2.17	1.25	0.35	14.27
Total		14.57	328	153	69	9	723

Overall, the growing stock in the CHAL was satisfactory and comparable with the previous study conducted by FRA Nepal (FRA 2014). The total number of stems (≥5cm DBH) in the CHAL was 539.06 million, and the number of stems per hectare was 723.7. The total basal area of live trees in the CHAL was 19.37 million m^2, and the average basal area was 26.01 m^2 ha^{-1}. The total stem volume of live trees was 48.18 million m^3 or 64.69 m^3ha^{-1} (Table 27).

Table 27: Growing stock per hectare in CHAL

S.N.	Stratum	No. of Plots	No. of stems (no./ha)	Basal Area (m^2ha^{-1})	Stem Volume (m^3ha^{-1})
1	DB	95	1016.50	31.03	60.14
2	DN	53	745.72	36.49	72.72
3	SB	116	630.18	18.26	60.29
4	SN	36	502.40	18.24	65.62
	Total/Average	300	723.70	26.01	64.69

The study found that most forest trees were young. In the middle hills, the diversity of tree species was greater than in the Plains/lowlands or High Mountains/Himalaya. The result indicates that most trees in all the strata are young and that there is the potential to enhance forest carbon stock by encouraging tree and vegetation growth and sustainable forest management.

4.3.5 Forest biomass

4.3.5.1 Aboveground tree biomass

Based on the analysis from the R-core development software, the dense needle-leaf forest stratum had the highest spread of above ground tree biomass. It is followed by the dense and sparse broadleaf forest strata. The sparse needle-leaf forest stratum had the lowest spread of above ground tree biomass. Figure 11 shows that there were few plots with extreme tree biomass values – indicating that there is the potential to enhance the tree biomass in the forest. The number of outlier plots is highest in the sparse broadleaf forest stratum. The median value of tree biomass is below the biomass value of 200 t ha^{-1} in dense broadleaf, sparse broadleaf, and sparse needle-leaf forest strata. Only the dense needle-leaf stratum had a median biomass value of more than 200 t ha^{-1}. The minimum values of tree biomass showed a uniform pattern in all four forest-strata, indicating that the minimum biomass for all strata does not vary significantly.

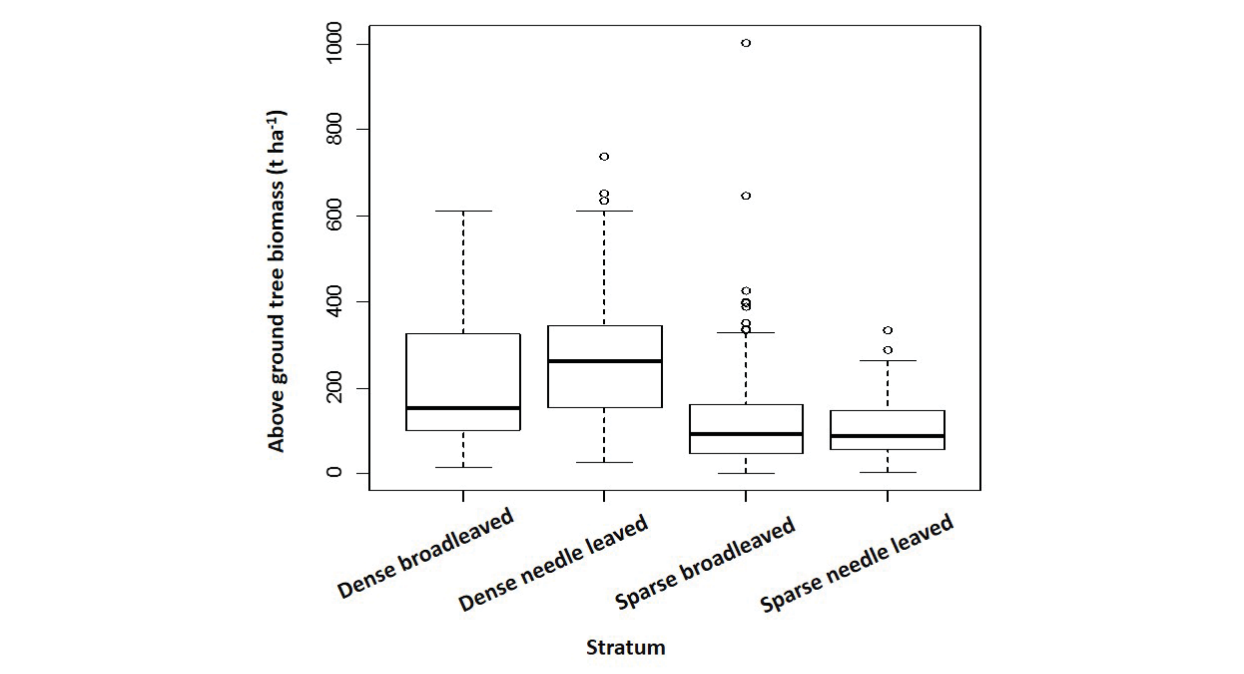


Figure 11: Box and whisker plot of AGTB in four strata

The average above ground tree biomass in CHAL forest was highest (279.71 t ha^{-1}) in the dense needle-leaf forest stratum and lowest (115 t ha^{-1}) in the sparse needle-leaf forest stratum. For dense broadleaf forest stratum, the standard deviation of the above ground tree biomass was highest at 144.44 with a confidence interval of 127.75. The standard error was within the acceptable limits (20%) in dense needle-leaf and sparse broadleaf forest strata indicating that the sampling had good accuracy. The sampling error was slightly higher (23%) than the acceptable limits in dense broadleaf and sparse needle leave forest strata suggesting the need to improve further the sampling in the future (Table 28).

Table 28: The summary statistics of sampling of trees in four strata

Strata	Mean AGB (ton/ha)	Std. Dev AGB	Std. error	95% confidence interval
DB	221.92	144.44	23	127.75
DN	279.51	111.29	17	101.04
SB	132.06	89.57	20	50.59
SN	115.00	47.44	23	95.35

4.3.5.2 Sapling biomass

The mean sapling biomass value was found to be highest (3.22 t ha^{-1}) in the dense broadleaf forest stratum and lowest (0.69 t ha^{-1}) in the dense needle-leaf forest stratum. Figure 12 shows that the dense broadleaf forest stratum has the most spread of sapling biomass (i.e. more than 70 t ha^{-1} in few plots), followed by sparse broadleaf forest stratum with more than 30 t ha^{-1} in few plots, while the dense and sparse needle-leaf forest strata have the lowest spread of sapling biomass values.

Furthermore, the dense broadleaf forest stratum has the highest outlier sapling biomass value, followed by the sparse broadleaf forest stratum showing the potential for biomass enhancement in broadleaf forests. Similarly, the outlier sapling biomass values in both dense and sparse needle-leaf forest strata were very low indicating a need to promote activities to enhance the sapling growth and sapling biomass in the needle-leaf strata.

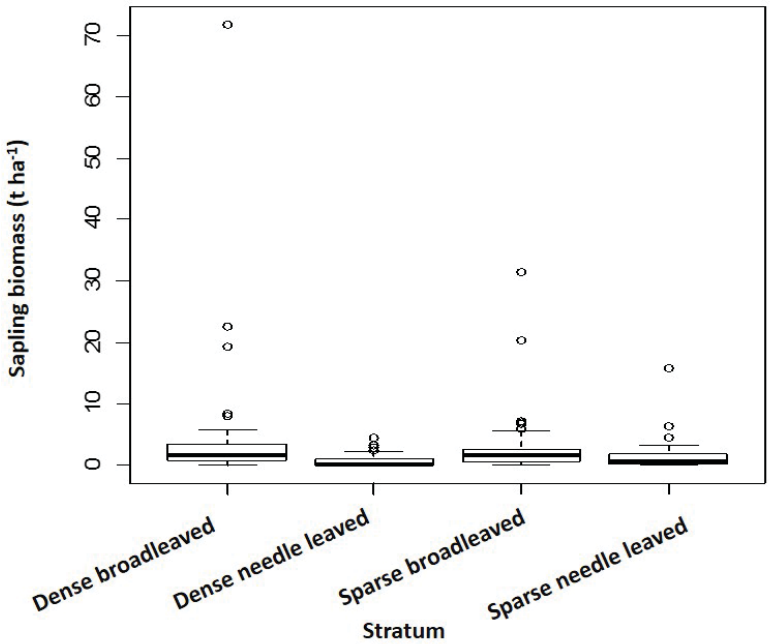


Figure 12: Box and whisker plot of sapling biomass in four strata

4.3.5.3 Shrub biomass

As shown in Figure 13, the sparse needle-leaf forest stratum has the highest spread of shrub biomass, followed by the dense broadleaf forest stratum. Similarly, the dense needle-leaf and sparse broadleaf forest strata have the lowest spread of shrub biomass, but the mean shrub biomass was highest (1.98 t ha^{-1}) in the dense needle-leaf forest stratum and lowest (1.03 t ha^{-1}) in the dense broadleaf forest stratum. However, the number of outlier plots of shrub biomass was highest (>40 t ha^{-1}) in the sparse broadleaf forest stratum followed by dense broadleaf forest stratum (> 20 t ha^{-1}) showing the potential to increase biomass in the broadleaf forest stratum.

Although the mean shrub biomass is the highest in the needle-leaf forest stratum, the potential to enhance shrub biomass was highest in the broadleaf forest stratum. The high shrub biomass in the needle-leaf forest is due to more canopy openings allowing more sunlight for the better growth of the under canopy (shrubs, herbs, and grasses), and less competition from the vegetation as compared to the broadleaf forests where the vegetation diversity is high. The shrub biomass in the Central Himalayan Forests was 0.247 t ha^{-1} in *Aesculus indica* forest, 0.984 t ha^{-1} in *Abies spectabilis* forest, and 1.712 t ha^{-1} in *Quercus leucotrichophora* forest (Adhikari *et al.* 1995), which are figures similar to the mean shrub biomass values calculated in CHAL.

4.3.5.4 Herb and grasses biomass

Figure 14 shows that the sparse needle-leaf forest and sparse broadleaf forest strata have the highest spread of herb and grass biomass, followed by the dense broadleaf and dense needle-leaf forest strata. Dense and sparse broadleaf forest strata have the highest outliers (i.e. more than 6 t ha^{-1} in few plots) showing the potentiality of herb and grasses biomass to that extent.

The mean biomass was highest (0.83 t ha^{-1}) in the sparse needle-leaf forest stratum and lowest (0.37 t ha^{-1}) in the dense broadleaf forest stratum (Table 29). The median value of the herb and grasses biomass was higher and more uniform in both strata of broadleaf forest. The needle-leaf forest stratum has a slightly lower median biomass value but exhibits a uniform pattern between both strata of the needle-leaf forest. The needle-leaf forest stratum has high herbs and grasses biomass as compared to a broadleaf forest, which might be due to openings in the canopy in needle-leaf forests as seen in other such studies conducted in the Central Himalayan

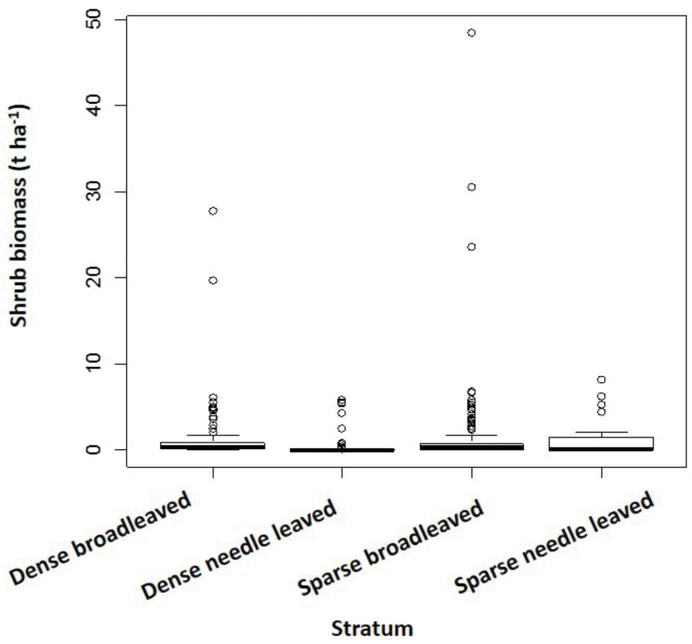


Figure 13: Box and whisker plot of shrub biomass in four strata

region of India. Chaturvedi (1983) reported total biomass production in the needle-leaf forest in the range of 1.63-2.57 t ha^{-1}. Similarly, Kubicek and Jurko (1975) reported aboveground herbaceous biomass production in the range of 0.45 to 1.37 t ha^{-1} for some temperate forests.

For the mixed broadleaf forest of Central Himalayan forest of India (Rana 1985), herb and grasses biomass values were reported up to 0.91 t ha^{-1}. As well, the shrub biomass in the High Altitude Himalayan forest of the Central Himalaya was 0.97 t ha-1, 0.79 t ha^{-1} to 0.75 t ha^{-1} respectively in *Aesculus indica, Abies spectabilis* and *Quercus leucotrichophora forests* (Adhikari *et al.* 1995), which are the best forests comparable with the herb and grasses biomass calculated in the present study.

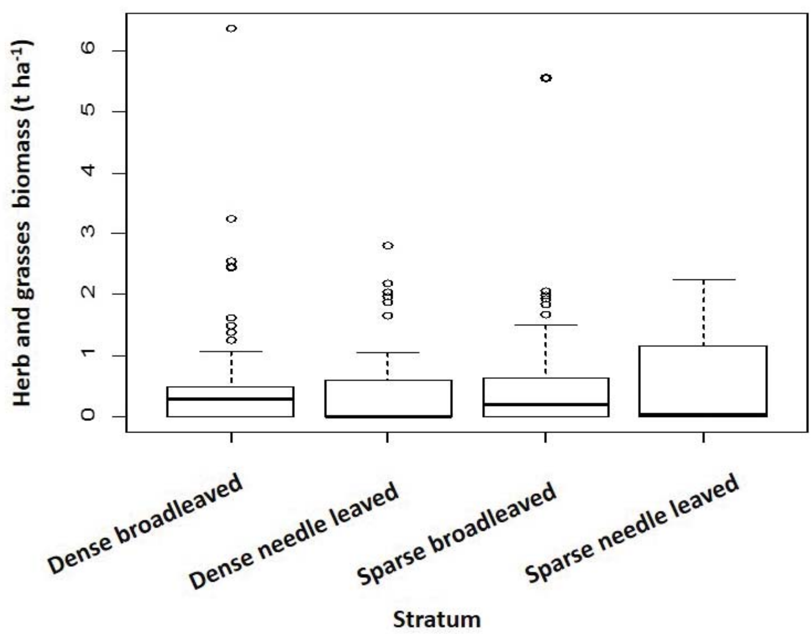


Figure 14: Box and whisker plot of herb and grasses biomass in four strata

4.3.5.5 Leaf litter biomass

Figure 15 suggests that the dense broadleaf forest stratum has the highest spread of leaf litter biomass followed by sparse broadleaf forest stratum, whereas the dense and sparse needle-leaf forest strata have the lowest spread of leaf litter biomass due to which the shape of the box and whisker plot is slightly contracted for needle-leaf forest stratum. The mean leaf litter biomass was the highest (3.88 t ha^{-1}) in sparse needle-leaf forest stratum and the lowest (3.02 t ha^{-1}) in dense needle-leaf forest stratum.

The dense and sparse broadleaf forest strata have the highest outliers in leaf litter biomass (i.e. up to 20 t ha^{-1} in few plots) showing the enhancement potentiality of leaf litter biomass to that extent in the forest. The dense and sparse needle-leaf forest has slightly lower (i.e., up to 15 t ha^{-1} in few plots) outliers in terms of the leaf litter biomass. The minimum leaf litter biomass values in all forest strata have a uniform pattern while it is different for the maximum leaf litter biomass values in all; however, the median values exhibit the uniform pattern in all strata.

A review of 44 published studies of Indian forests documented total leaf litter in the range of 4.3 to 8.5 t ha^{-1} and annual from 3.4 to 6.9 t ha^{-1} (Dadhwal *et al.* 1997). Vogt *et al.* (1986) compiled a range of 2.44 to 9.44 t ha^{-1} for various forest types of the world. If compared the result of CHAL, the litter biomass lies within the range of Indian Himalaya and an average range of world's forest.

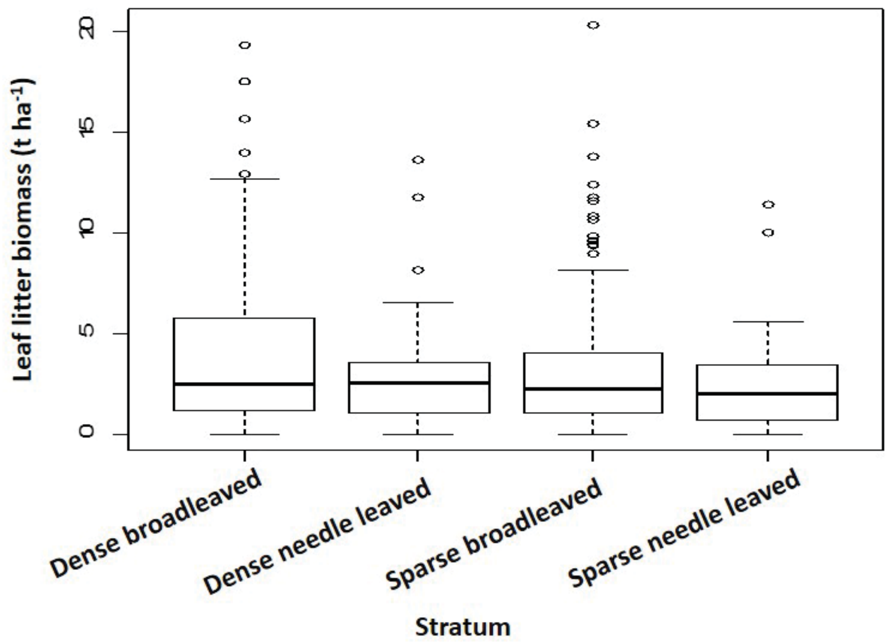


Figure 15: Box and whisker plot of leaf litter biomass in four strata

4.3.5.6 Above and below ground vegetation biomass

Table 29 shows the strata-wise above and belowground vegetation biomass. Among the four strata, the biomass of live trees in dense needle-leaf stratum was the highest (335.41 t ha^{-1}) and that in sparse needle-leaf the lowest (138.0 t ha^{-1}). The highest biomass quantity in the dense needle-leaf forest could be because those forests are generally found in the high-altitude and relatively inaccessible areas with fewer human activities. The mean biomass of live trees in CHAL is 224.54 t ha^{-1}, which contributes almost 97% of the total biomass in CHAL. Leaf litter contributes to about 1.5% and the shrubs, herbs, and grasses contribute to the remaining biomass. The average biomass in CHAL was 231 t ha^{-1}.

Table 29: Strata wise above and below ground biomass

S.N.	Biomass pool	Strata wise biomass (t ha^{-1})				Average biomass (t ha^{-1})	Contribution (%)
		DB	DN	SB	SN		
1	*Biomass-tree*	266.3	33.5.41	158.77	138.00	224.54	96.9
	Above ground	221.92	279.51	132.06	115.0	187.12	
	Below ground	44.38	55.90	26.41	23.00	37.42	
2	*Biomass-sapling*	3.22	0.70	2.29	1.47	1.92	0.83
3	*Biomass- shrub*	1.03	1.98	1.17	1.19	1.34	0.58
4	*Biomass- herbs and grasses*	0.37	0.60	0.42	0.83	0.55	0.24
5	*Biomass-leaf litter*	3.20	3.02	3.44	3.88	3.38	1.45
Total		**274.12**	**341.71**	**165.79**	**145.37**	**231.7**	**100**

4.3.6 Forest carbon stock

4.3.6.1 Above and below ground forest carbon stock

Using a conversion factor of 0.47 for carbon and 3.67 for CO_2, the calculated biomass (Table 29) converted into carbon and CO_2 respectively. The carbon and CO_2 of ABG and BGB have been presented in Table 30.

Table 30: Strata and pool wise carbon stock (tC ha^{-1})

S.N.	Stratum	Above ground tree	Below ground tree	Sapling	Shrub	Herb and grass	Leaf litter	Total
1	DB	104.30	20.85	1.51	0.48	0.17	1.50	128.81
2	DN	131.36	26.27	0.32	0.93	0.28	1.41	160.57
3	SB	62.06	12.41	1.07	0.54	0.19	1.61	77.88
4	SN	54.05	10.81	0.69	0.55	0.39	1.82	68.31
Average		**87.94**	**17.58**	**0.89**	**0.62**	**0.257**	**1.58**	**108.89**

Table 30 shows that the average above and belowground carbon (tree, sapling, shrub, herbs and grasses and leaf litter) was estimated to be 108.89 tC ha^{-1}. The mean carbon stock in dense needle-leaf forest was highest (160.57 t C ha^{-1}) followed by dense board leaf forest (128.81 $tCha^{-1}$). Among the carbon pools, above ground tree pool biomass has the highest carbon stock i.e. 87.94 $tCha^{-1}$, while the herbs and grass pool has the lowest carbon stock, 0.257 tC ha^{-1}.

4.3.6.2 Soil organic carbon

Table 31 shows that the mean soil bulk density ranged from 0.74 to 1.02 gm cc^{-1} across the strata. The mean soil bulk density was the highest (1.02 gm cc^{-1}) in sparse needle-leaf forest stratum and lowest (0.74gm cc^{-1}) in dense broadleaf forest stratum. This shows that the Soil in the sparse needle-leaf stratum is compact whereas that in the dense broadleaf stratum are loose.

Similarly, the mean Soil organic carbon percentage ranged from 2.69 to 4.77 across all four strata in CHAL. It is the highest (4.7%) in dense broadleaf forest stratum and the lowest (2.69%) in sparse needle-leaf forest stratum. Soil organic carbon percent for all strata is presented in Table 31. It is clearly seen that soil with the lowest bulk density has the highest soil organic carbon percentage and vice versa.

Table 31: Soil organic carbon

Strata	Soil bulk density (gm/cm^3)	SOC (%)	Mean SOC (tC ha^{-1})	Std. Dev AGB	Std. error	95% confidence interval
DB	0.74	4.77	100.03	27.58	11.1	23.96
DN	0.96	3.01	84.28	19.94	12.8	39.35
SB	0.83	3.82	90.14	26.28	10.1	19.28
SN	1.02	2.69	74.67	18.74	10.9	30.53

The soil organic carbon is higher in the broadleaf forests compared to the needle-leaf forests. This might be due to the higher leaf litter decomposition rates and rapid nutrient cycle in the broadleaf forests and generally the warmer climate as compared to the needle-leaf forests in the temperate region. The summary statistics reveals that the standard deviation was the highest 27.58 for dense broadleaf forest stratum. In contrast, the confidence interval at (95%) was highest 39.35 for dense needle-leaf forest stratum. The standard error was almost similar and remained below (13%) in all the four forest strata in CHAL indicating that the soil sampling was accurate and precise enough for the measurement and analysis. Similarly, the analysis of soil organic carbon is presented in Box and whisker plot as given in Figure 16.

The Figure 16 shows that soil organic carbon values of the sampling plots spread in a wide range in dense broadleaf forest stratum compared to sparse needle-leaf forest stratum. This result shows that the enhancement potentiality of the soil organic carbon in dense broadleaf forest stratum was found to be higher up to 200 tC ha^{-1}. On the other hand, the sparse and dense needle-leaf forest also has an opportunity to enhance forest carbon converting them into mixed forests.

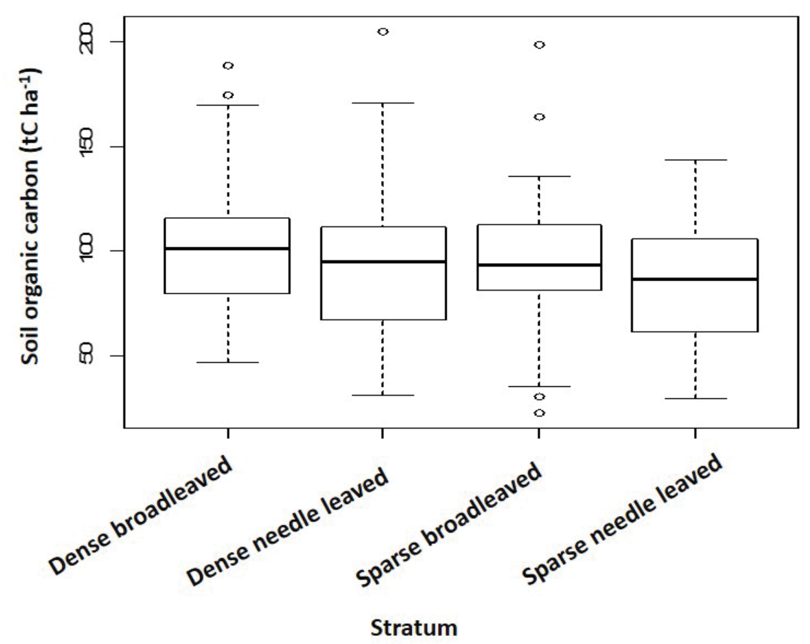


Figure 16: Box and whisker plot of soil organic carbon in four strata

4.3.6.3 Total forest carbon stock

a) Strata and pool wise carbon stock (per hectare)

The average forest carbon stock per hectare was determined by summing up the ABG, BGB, and soil organic carbon (Table 32).

Table 32: Strata and pool wise carbon stock (tC ha^{-1})

S.N.	Stratum	Above ground tree	Below ground tree	Sapling	Shrub	Herb and grass	Leaf litter	SOC	Total
1	DB	104.30	20.85	1.51	0.48	0.17	1.50	100.03	228.84
2	DN	131.36	26.27	0.32	0.93	0.28	1.41	84.28	244.85
3	SB	62.06	12.41	1.07	0.54	0.19	1.61	90.14	168.02
4	SN	54.05	10.81	0.69	0.55	0.39	1.82	74.67	142.98
	Average	87.94	17.58	0.89	0.62	0.257	1.58	87.28	196.17

The mean forest carbon stock in CHAL was 196.17 tC ha^{-1} while the strata-wise mean carbon stock was 228.84 tC ha^{-1} in dense broadleaf forests, 244.85 tC ha^{-1} in dense needle-leaf, 168.02 tC ha^{-1} in sparse broadleaf, and 142.98 tC ha^{-1} in sparse needle-leaf forest stratum.

b) Total forest carbon stock in CHAL

Table 33 shows the weighted mean carbon stock value for dense and sparse strata and for overall CHAL area. The weighted mean carbon values for the dense and sparse strata was 236.11 and 157.54 tC ha^{-1} respectively whereas that for overall weighted mean carbon stock in CHAL was 197.8 tC ha^{-1}.

Table 33: Weighted mean carbon stock

<table>
<tr><th>Strata</th><th>Mean carbon (tC ha⁻¹)</th><th>Area (ha)</th><th>Carbon stock (tC)</th><th>Total carbon stock (tC)</th><th>Weighted mean in strata (tC ha⁻¹)</th><th>Weighted mean (tC ha⁻¹)</th><th>CO₂ e (tC ha⁻¹)</th></tr>
<tr><td>DB</td><td>228.8</td><td>208,400.0</td><td>47,690,256.0</td><td rowspan="2">90,129,861.7</td><td rowspan="2">236.1</td><td rowspan="4">197.8</td><td rowspan="4">725.93</td></tr>
<tr><td>DN</td><td>244.9</td><td>173,329.0</td><td>42,439,605.6</td></tr>
<tr><td>SB</td><td>168.9</td><td>204,321.0</td><td>34,499,600.8</td><td rowspan="2">57,207,398.5</td><td rowspan="2">157.5</td></tr>
<tr><td>SN</td><td>143.0</td><td>158,818.0</td><td>22,707,797.6</td></tr>
</table>

When comparing the forest carbon stock of CHAL with estimates for different forest types of the world and the forests of different landscapes/watersheds of Nepal, the mean weighted forest carbon value (197.80 tC ha^{-1}) was within the range of forest carbon stock estimated for the seven Central Himalayan Forests of Hindu Kush Himalayan region (166.8-440 tC ha^{-1}) (Rana *et al.* 1999). It was lower than the values estimated in the Central Himalayan Forest of India (250-300 tC ha-^{1}) (Singh and Singh 2006) and the world's tropical forests (285.82 tC ha^{-1}) (Malhi *et al.* 2000). The forest carbon stock of CHAL was about the value estimated for Kayarkhola watershed, Chitwan 283.27 tC ha^{-1}; Ludikhola watershed, Gorkha 205.43 tC ha^{-1}; and Charnawati watershed, Dolakha 175.04 tC ha^{-1} (ANSAB 2014). The forest carbon value of CHAL was higher than the forest carbon stock estimated for Terai forests (124.14 tC ha^{-1}) and Churia forests (116.94 tC ha^{-1}) (FRA 2014) and lower than the forest carbon stock that of TAL (237.74 tC ha^{-1}) (WWF Nepal 2011).

Based on weighted mean calculated for each stratum and overall CHAL, Table 34 presents total carbon and CO_2 equivalent in million ton. Total carbon stock was found higher in dense broadleaf forests (151.11 million ton) and lower in sparse needle-leaf forests (115.16 million ton) and 540.1 million ton in total.

Table 34: Total stock of carbon and CO_2

S.N.	Stratum	Area of Stratum (00,000 ha)	Carbon stock (million ton)	Total Carbon dioxide equivalent (million tCO_2e)
1	DB	2.08	41.175	151.11
2	DN	1.73	34.246	125.68
3	SB	2.04	40.369	148.15
4	SN	1.59	31.378	115.16
Total		7.45	147.168	540.1

c) Forest carbon distribution in dense and sparse forest

As shown in Figure 17, among the three different carbon pools measured, tree holds the highest carbon stock in both dense broad and needle-leaf forest strata. The soil is the second largest carbon pool followed by the below ground pool, and the saplings, shrubs, litter and herb carbon pool respectively. Moreover, below ground carbon stock in the dense needle-leaf forest is high compared to the dense broadleaf forest. In contrast, in a sparse forest, the soil carbon pool holds more than half of the total forest carbon stock. Figure 18 further shows that the percentage of carbon in the soil is 54.90 in sparse broadleaf and 55.62 in sparse needle-leaf. The tree holds only 35.9% of carbon in the sparse broadleaf and 35.11% in the needle-leaf forest stratum. The proportion of carbon stock in the below ground pool is almost the same in both strata at 7.18% and 7.02% respectively.

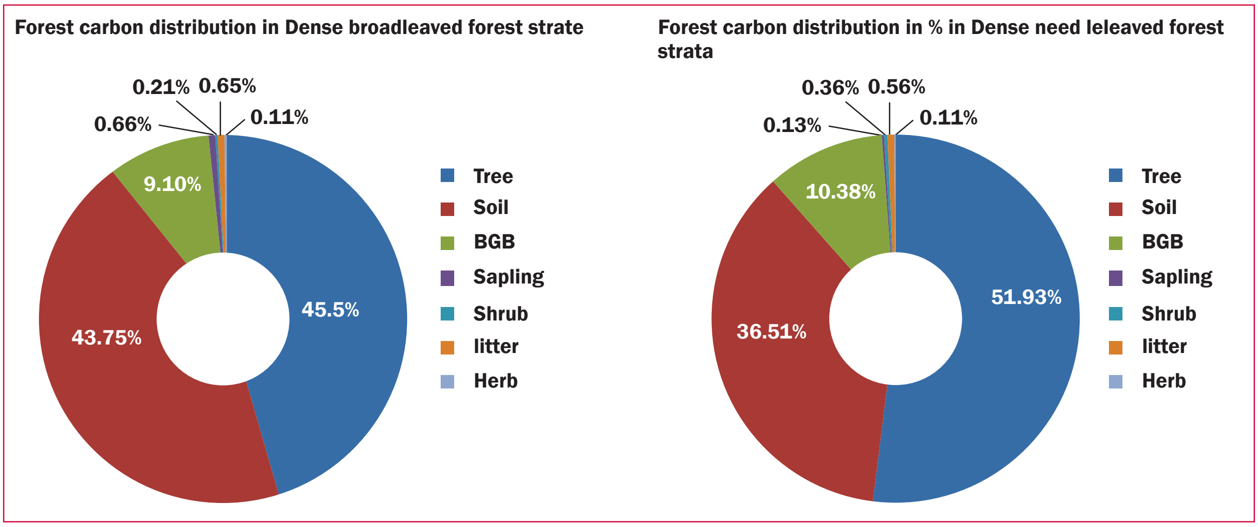


Figure 17: Strata wise proportion of carbon in dense broad-leaf and needle-leaf forest

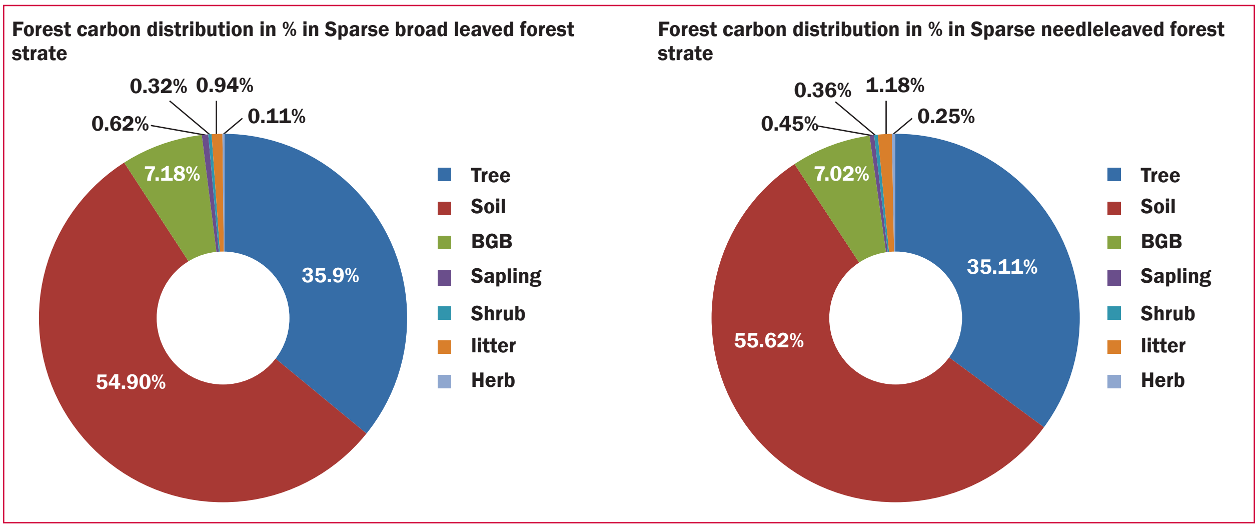


Figure 18: Strata wise proportion of carbon in sparse broad-leaf and needle-leaf forest

4.3.6.4 Forest carbon sequestration potential

Carbon sequestration is the removal of CO_2 from the atmosphere into sinks where it can be stored indefinitely. The total forest carbon sequestration potential in CHAL was 9.66 million ton Carbon dioxide equivalent (million tCO_2e) (Table 35).

Table 35: Total forest carbon sequestration potential

S.N.	Stratum	Area of Stratum (ha)	Sequestration potential in CHAL		
			Carbon sequestration ($tC\ yr^{-1}$)	Carbon dioxide sequestration ($tCO_2e\ yr^{-1}$)	Carbon dioxide sequestration (Million ton $CO_2e\ yr^{-1}$)
1	DB	208,400	835,336.67	3,065,685.57	3.07
2	DN	17,339	509,731.70	1,870,715.34	1.87
3	SB	20,4321	818,986.68	3,005,681.10	3.01
4	SN	158,818	467,057.27	1,714,100.17	1.71
Total		744,868	2,631,112	9,656,182	9.66

The analysis shows that the annual carbon dioxide sequestration of CHAL was found highest in dense broadleaf forests (3.07 million ton $CO_2e\ yr^{-1}$) and followed by sparse broadleaf forests (3.01 million ton CO2e yr^{-1}), dense needle-leaf forests (1.87 million ton CO2e yr-1) and sparse needle-leaf forests (1.71 million ton CO2e yr^{-1}) respectively.

4.3.6.5 Disturbances, risk and degradation of forests

Of 300 permanent sample plots measured in the CHAL, 282 plots are natural forest vegetation areas, and 18 plots are man-made forest plantations. Altogether six major disturbance indicators; forest fire incidences, lopping, grazing in the forest, firewood collection, timber extraction and soil erosion were recorded in the forest plots (Figure 19).

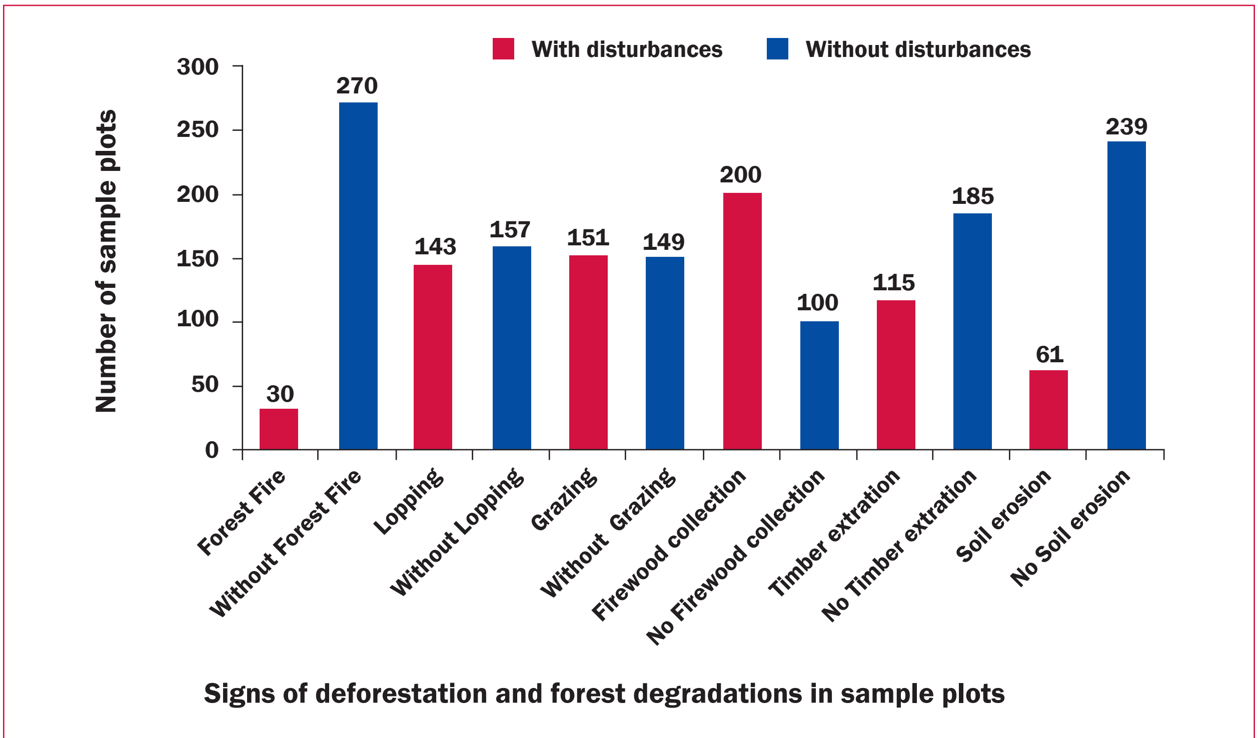


Figure 19: Incidences of forest disturbances in the permanent sample plots

Figure 20 reflects the signs of forest disturbances in the permanent sample plots. About (35.33 %) of forest plots had some kinds of disturbances as mentioned above while (64.67%) of forest plots were free from the disturbances. Despite this, firewood collection, grazing, and lopping are the major threats of forest degradation in CHAL. About (66.7%), (53.3%), (47.7%) and (38.3%) of forest plots seems to be having firewood collection, uncontrolled grazing, lopping and timber extraction as factors of forest degradation (Figure 22).

4.3.7 Forest biodiversity

4.3.7.1 Tree species diversity

Altogether 145 plant species[3] were recorded in CHAL. Out of 145 tree species, 115 genera and 61 families are represented in CHAL. Among them, 88 percentage of the species were found in broadleaf forests and the rest in needle-leaf forests. Similarly, the analysis presented major top four species for each stratum as given in (Table 36).

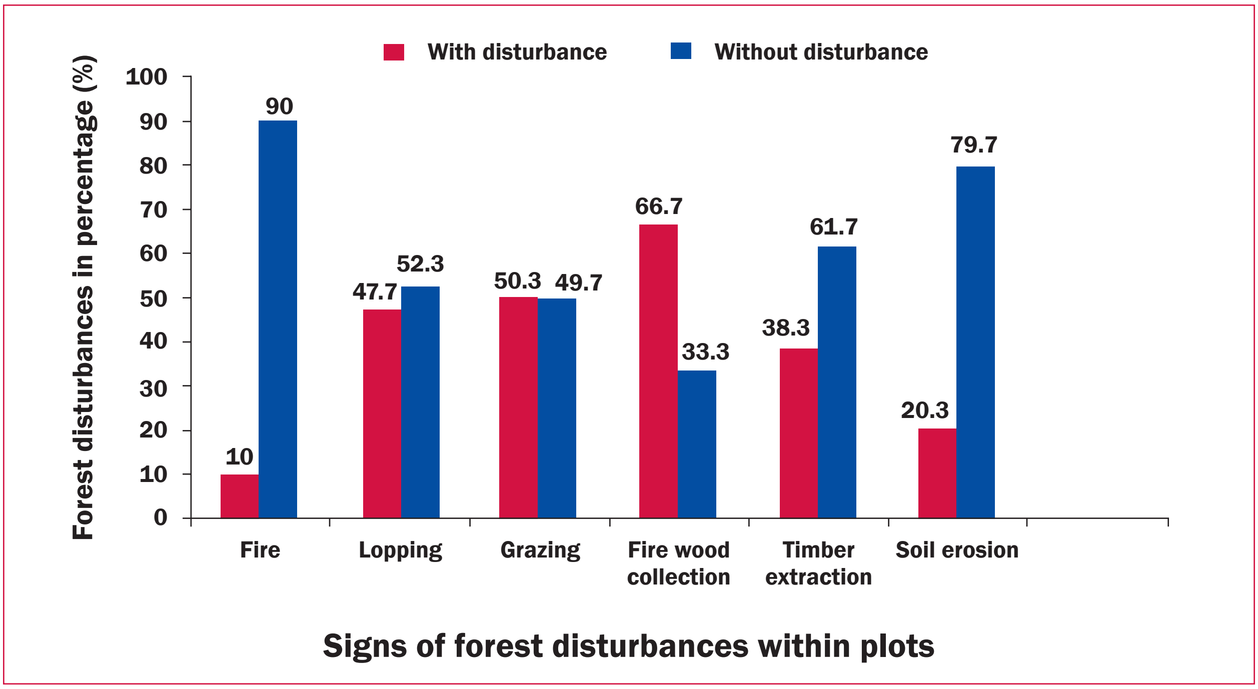


Figure 20: Signs of forest disturbances in permanent sample plots

Table 36 shows that Shorea robusta appeared to be the most dominant and the most frequently occurring plant species in both dense and sparse strata of broadleaf forests. The second most common plant species was *Schima wallichii* and *Castanopsis indica* whereas *Alnus nepalensis, Rhododendron spp*. *Lyonia ovalifolia, Eurya acuminata,* and *Engelhardia spicata* were the most commonly occurring plant species in dense and sparse strata of broadleaf forests in CHAL. The dense and sparse needle-leaf forest strata had a different dominant floristic composition compared to the broadleaf forest. *Pinus roxburghii, Pinus wallichiana,* and *Pinus patula* were the most frequently occurring tree species in needle-leaf forests. *Schima wallichii and Rhododendron spp.* were the plant species commonly found in both broadleaf and needle-leaf forests of the CHAL.

4.3.7.2 Shrub species diversity

A total of 85 different shrub species were recorded in all four strata of CHAL. Likewise, the tree species, the diversity of shrub species was also found higher in strata of broadleaf forests than in needle-leaf forests. There were 52 different shrub species recorded in the dense broadleaf forest and 33 in needle-leaf forests (Annex 9).

3 The total number of plant species is likely to decrease once the botanical names of all plant species are confirmed because in many cases, the same plant species might have different local names within different communities and sites throughout the CHAL.

Table 36: Rank of four mostly observed plant species

Stratum	Rank	Life forms		
		Tree	Sapling	Regeneration
DB	1	Sal *(Shorea robusta)*	Sal *(Shorea robusta)*	Sal *(Shorea robusta)*
	2	Chilaune *(Schima wallichii)*	Katus *(Castanopsis indica)*	Katus *(Castanopsis indica)*
	3	Katus *(Castanopsis indica)*	Chilaune *(Schima wallichii)*	Chilaune *(Schima wallichii)*
	4	Utis *(Alnus nepalensis)*	Jhigune *(Eurya acuminata)*	Mahuwa *(Engelhardia spicata)*
DN	1	Khote salla *(Pinus roxburghii)*	Gobre salla *(Pinus wallichiana)*	Gobre salla *(Pinus wallichiana)*
	2	Gobre salla *(Pinus wallichiana)*	Chilaune *(Schima wallichii)*	Guras *(Rhododendron spp.)*
	3	Pate salla *(Pinus petula)*	Khote salla *(Pinus roxburghii)*	Loth salla *(Taxus baccata)*
	4	Angeri *(Lyonia ovalifolia)*	Loth salla *(Taxus baccata)*	Pate salla *(Pinus petula)*
SB	1	Sal *(Shorea robusta)*	Sal *(Shorea robusta)*	Sal *(Shorea robusta)*
	2	Chilaune *(Schima wallichii)*	Katus *(Castanopsis indica)*	Katus *(Castanopsis indica)*
	3	Katus *(Castanopsis indica)*	Chilaune *(Schima wallichii)*	Chilaune *(Schima wallichii)*
	4	Guras *(Rhododendron spp.)*	Angeri *(Lyonia ovalifolia)*	Guras *(Rhododendron spp.)*
SN	1	Khote salla *(Pinus roxburghii)*	Chilaune *(Schima wallichii)*	Gobre salla *(Pinus wallichiana)*
	2	Gobre salla *(Pinus wallichiana)*	Khote salla *(Pinus roxburghii)*	Chilaune *(Schima wallichii)*
	3	Chilaune *(Schima wallichii)*	Gobre salla *(Pinus wallichiana)*	Khote salla *(Pinus roxburghii)*
	4	Guras *(Rhododendron spp.)*	Khote salla *(Pinus roxburghii)*	Dhupi salla *(Juniperus Indica)*

4.4 Climate, Socio-Economic and Environment Benefits of REDD+

4.4.1 Climate benefits of REDD+

REDD+ will improve forests status and increase stocking rates of vegetation biomass and carbon quantity in forests. Due to forest improvements, the following key possible climatic benefits could be achieved from CHAL areas participating in REDD+ process.

- Contribute to mitigate global climate change through local actions to increase carbon sequestration capacity of forests.
- Reduce landslide incidences in the region by increasing vegetation in the area. Tree roots anchor soil and reduce erosion and landslides.
- Reduce possible risk of flood damage by increasing vegetation in the area. Increased vegetation cover through REDD+ activities plays a major role in reducing current groundwater levels and increase the absorption of water.
- Support for sustainable forests ecosystems and maintain natural spring and smoothness in recharge water cycles in the area.
- Improve water cycles, as well as microclimate (rainfall and temperature patterns) of the local area.

4.4.2 Socio-economic benefits of REDD+

The REDD+ mechanism provides incentives for protecting and enhancing forests. It has the potential to improve the socio-economic situations of communities at the local level. Both benefits and risks are listed below.

- Generate subsistence uses of forest resources from the sustainable management of the forests.
- Create additional income from carbon benefits and use it for poverty alleviation and other development activities at the local level.
- Develop new institutional set up for REDD+ activities and benefit distribution mechanisms, which will build capacities of local people.
- Empower local and marginalized community members through REDD+ financial and social benefits.
- Establish linkages between various related organizations related to the REDD+ project.

Possible sacrificed benefits

- Although government managed forests, religious forests, leasehold forests, community forests and private forests are major existing forest management regimes, REDD+ project activities in these forests may increase the cost of management.
- In order to increase carbon stock, there is a need to reduce extraction of forest products. Due to reduced extraction from forests, community members are required to either buy the products or adopt less unsustainable practices. This change in behavior requires additional costs of local people.
- REDD+ is a new mechanism, so the participation of all stakeholders in decision-making processes and project activities is crucial. Local people are required to attend such meetings and activities on a voluntary basis.

4.4.3 Environmental benefits of REDD+

The REDD+ project could provide several environmental benefits. In CHAL areas, REDD+ projects will encourage local people and stakeholders to achieve following environmental benefits:

- **Improve degraded forests:** Between 1978 and 2010, a total of 283 square km of forest were degraded in the CHAL region. Out of the existing forests in CHAL areas, (48%) of total broadleaf forests and (42%) of total coniferous forests are sparse types. The REDD+ project can increase carbon stock by improving the quality of sparse forests by reducing disturbances and improving activities.
- **Improve habitat for endangered species:** An increase of forest cover in the area can provide habitats for various endangered wild wife and plants species located in Mid-hill and Mountainous regions. About 69% of listed plants of Nepal are in the central part of Nepal where the CHAL is located. Similarly, most of the fauna listed in CITES are found in CHAL areas except water buffalo and swamp deer. The region also provides habitats for various birds, reptiles, and mammals.
- **Reduce floods and landslides in the region:** Increasing vegetation in riverbanks and degraded forests of upstream areas will help reduce water current, increase absorption of water and reduce the risk of floods and landslides. This ultimately reduces the possible loss of infrastructure, human and natural assets of the region.
- **Provide multiple benefits of forests:** Forests provide various species of timber and non-timber forest products including wild foods for local people. Besides, it improved forests provides carbon benefits and other co-benefits such as biodiversity, livelihood generation and adapting to changing climate situation.
- Diverse forests can also provide local people with food supplements during times of food insecurity.

Ginger cultivation, Bhumipujne Tisndunge CFUG, Lamachaur VDC, Kaski
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Chapter 5

Conclusion and Way Forward

The study team used a combination of remote sensing and ground-based inventory to account forest coverage and forest carbon stock of Chitwan-Annapurna Landscape. It employed trained forest technicians and local resource persons. The socio-economic and drivers of deforestation and forest degradation were assessed using rapid socio-economic survey tools, such as focus group discussions, key informant interview, experts/ stakeholder consultation, and literature review. Further, the team used geospatial analysis and plot level data to explore and verify the information regarding the drivers of deforestation and forest degradation.

CHAL has 649,496 households with diverse social, economic, cultural background with the density of 138.23 households per square kilometer. The land holding per household is less than 1 hectare in average. There is increasing use of LPG and other alternative energy sources. However, 72.4% of households are completely dependent on fuelwood to fulfill their household energy demand. As a result, fuelwood collection is a major driver of forest degradation in the area.

The weighted mean baseline carbon stock in CHAL is 725.93 $tCO_2e\ ha^{-1}$ with the carbon value for the dense and sparse strata being 236.11 $tC\ ha^{-1}$ (866.52 $tCO_2e\ ha^{-1}$) and 157.54 $tC\ ha^{-1}$ (578.17 $tCO_2e\ ha^{-1}$) respectively. The total baseline forest carbon stock was 147.17 million tC (540.1 million tCO_2e) with an average of 197.8 tC ha^{-1} in CHAL. The strata-wise average carbon stock was highest for the dense needle-leaf forest (244.85 $tC\ ha^{-1}$) followed by dense broadleaf forest (228.84 $tC\ ha^{-1}$), sparse broadleaf (168.02 $tC\ ha^{-1}$) and sparse needle-leaf (142.98 $tC\ ha^{-1}$).

The CO_2 sequestration potential was 2.63 million $tC\ yr^{-1}$ (9.66 million $tCO_2e\ yr^{-1}$) in CHAL, where the dense broadleaf contributes the highest value (0.83 million tC) followed by sparse broadleaf (0.82 million tC), dense needle-leaf (0.51 million tC), and sparse needle-leaf forests (0.47 million tC). The forest carbon stock and sequestration rates vary depending on forest type, vegetation, and age of stand, ecological zone, altitude, aspects, and several other ecological factors. Thus, the forests in CHAL need silviculture operations in order to stimulate tree growth, maintain, and conserve forest biodiversity. The intensification of agriculture farming is necessary to make forest use more sustainable, promote alternative energy to reduce the fuelwood consumption, conserve forest biomass, and enhance the CO_2 sequestration potential in CHAL.

The study, based on the results concludes that diverse social, cultural and ecological settings and highly dependent on forest resources have invited different anthropogenic risks such as firewood collection, uncontrolled grazing and lopping, illegal timber extraction and soil erosion and landslides of forest deforestation and forest degradation. Thus, the REDD+ project has an enormous potential to contribute to the maintenance and enhancement of forest carbon benefits and the co-benefits of biodiversity conservation, livelihood generation, and climate change adaptation in CHAL. This would be achieved through the conversion of shrubland and grassland into forests promoting natural regeneration and plantations; improving value chains for non-timber forest products, pastoralism, and improved grazing; and bringing national forests under the community control or managed forests.

In order to initiate REDD+ readiness activities in CHAL, this study suggests the following recommendations:

Build capacity of communities and other relevant stakeholders at the local level: Involvement of local communities in forest carbon assessment and other activities of REDD+ reduce the costs and increase the ownership of the process. Other relevant stakeholders such as government line agencies (district forest office), forest user groups, district FECOFUN chapters and local NGOs working in conservation field could contribute to raising awareness, develop local capacity, carbon measurement, and the establishment of the database at the subnational level. Thus, periodic capacity building activities are crucial to enhancing and refresh the knowledge and skills of forest management units and other relevant stakeholders for participating in the REDD+ process. The experience of the REDD+ pilot project and other projects has produced a pool of trained individuals and capacitated organizations, and they can act as trainers in these areas.

Address permanency and leakage: The districts of Chitwan-Annapurna Landscape that have high population density have a high rate of deforestation and forest degradation. While initiating REDD+ activities, it is important to analyze the drivers of deforestation and forest degradation due to the local forest dwellers and develop measures to promote better livelihoods and sustainable forest management, which could ensure permanency and address leakage issues. Better permanency could be supported by options to develop farm forest enterprises, such as cultivation of NTFPs, promotion of ecosystem-based commercial agriculture, and support to ongoing activities. These include ecotourism for enhancing income and employment among forest-dependent people so that their occupation could shift to other activities, which maintain sustainability of the resources and improve the livelihood condition of the local forest dependent people.

Ensure participation of key stakeholders: Multiple stakeholders need to be involved in the REDD+ mechanism. Key stakeholders include government organizations, which are responsible for managing forests and protected areas, CFUGs, committees for leasehold forest management, private forest growers, non-government organizations working in forestry sectors, forest-based enterprises, as well as research institutions. All stakeholders need to play different roles in REDD+ projects. REDD+ initiatives, therefore, need to incentivize those stakeholders for carbon enhancement with proper participation and development of equitable benefit distribution mechanisms. Policies and plans could be developed by considering these aspects to ensure the sustainability of REDD+ projects. Learning from the REDD+ pilot project implemented by ANSAB, ICIMOD and FECOFUN could be used for building an institutional and benefits sharing mechanisms for REDD+ at a landscape level.

Improve forest governance: Currently, community forest user groups (CFUGs) manage about 60% of the total forest in CHAL. In order to mainstream carbon benefits in community forestry and reduce the transaction costs, the community forestry guideline should be revised to include the REDD+ provisions. This should be included into the operational plans of CFUGs. The work to measure forest carbon can be merged with periodic forest inventory being done by CFUGs during the handing over and renewal of the operational plans.

If new institutions are formed at the landscape level for starting REDD+ activities, proper mechanisms for forest governance should be developed to involve the local people. This could ensure the current level of participation of the local people with decision-making power and fair and equitable benefit-sharing.

For developing a fair benefits sharing mechanism, zoning of CHAL according to dominant species and canopy cover is helpful. The carbon stock in forests varies by the size, biomass, carbon sequestration potential, and growth rate of the dominant vegetation types and site productivity. It is helpful to zone forests according to dominant vegetation types during benefit sharing mechanisms that would facilitate fair performance-based payment mechanisms in REDD+ projects. The productivity of the sites is important as biodiversity and ecosystem services require different conditions and the needs may vary according to different sites.

Reduce dependency on forest resources: Local people are using forests and forest resources including timber, grasses, and NTFPs for various needs including household energy. It is necessary to adopt and promote appropriate alternative means for household energy to ensure permanency and to control possible leakages due to REDD+ initiatives. Some alternatives to reduce fuel-wood dependency include biogas, improved cooking stoves (ICS), and solar energy. Similarly, encouraging the plantation of trees and grasses on available fallow land can provide supplementary resources other than the forest. Some upfront financial support could be provided to the households for these alternatives.

Reduce use of forests for infrastructure development: There is a common practice in forest communities to use forest resources and land for the construction of roads, irrigation canals, schools, temples, and other development-related construction projects. These activities have been reducing forest areas and should be controlled for the reduction of the loss of forest land and ensure optimal benefits from REDD+. Coordination between different stakeholders including ministries and other government bodies is required for finding alternatives other than forest areas for the development of infrastructures.

Promote plantation and conservation-focused programs: The CHAL area has different compositions of sparse and dense canopy forests. There is great potential to increase carbon stock by promoting forest conservation activities and the planting of trees. The REDD+ project needs to develop a plan to enhance carbon stock through the plantation of appropriate trees and implementation of conservation measures.

Promote multiple species for carbon benefits: There are possibilities to promote high biomass carbon yielding trees in forest areas for REDD+ carbon benefits. This sort of forest management for REDD+ carbon benefits could yield fewer benefits for other forest ecosystems as it does not necessarily enhance the biodiversity in forests. However, conservation of diversity is important in protecting biodiversity and the habitats of various native plant species and wildlife. This could be addressed by promoting multiple species in the forests and establishing local or international payment linkages by integrating REDD+ to non-carbon benefits in the forests.

Confluence of Trisuli and Seti Gandaki

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Young *sal* leaves, Jumdanda Jhapri CFUG, Jumdanda, Tanahu

Annexes

Annex 1: Characteristics of satellite data used in the study

Year	Satellite	Sensor	Data acquisition date	Path/Row
1970's	Landsat-3	MSS	3-Dec-76 28-Oct-76 7-Jul-79 25-Feb-75	152/040 152-041 153/040 153/041
1990's	Landsat-5	TM	10-Dec-88 31-Oct-89 10-Nov-90 11-Jul-89	140/041 141/041 142/040 142/041
2000's	Landsat-5	TM	22-Nov-00 27-Dec-01 13-Dec-99 13-Dec-99	140/041 141/041 142/040 142/041
2010's	Landsat-5	TM	9-Dec-09 7-Nov-09 7-Apr-10 18-Feb-10	140/041 141/041 142/040 142/041

Annex 2: Spectral bands of landsat images

Spectral Mode	Spectral bands	Spectral range (μm)	Spatial resolution (m)
Multispectral	Blue	0.45 – 0.50	30 x 30
	Green	0.52 – 0.60	30 x 30
	Red	0.63 – 0.69	30 x 30
	NIR	0.76 – 0.90	30 x 30
	SWIR	1.55 – 1.75	30 x 30
	FIR	2.08 – 2.35	30 x 30

Annex 3: Forms and formats for forest data collection

दिगो कृषि तथा जैविक श्रोतका लागि एशियाली नेटवर्क (एन्साब)

वन श्रोत सर्भेक्षण फारम

प्लट संख्या: ______

स्ट्राटा: ______

जिल्ला: ______

मिति : २० / /

टिपोटकर्ताको नाम : ______

अन्य टोली सदस्य : ______

नक्सा प्लटको स्थान देखाउने खेस्रा नक्सा	प्लटको केन्द्र बिन्दुको reference

१. पृष्ठभूमि जानकारी

व.उ.स.को नाम : ______

वनको नाम : ______

ब्लकको नाम र संख्या : ______

अवस्थिती (जि.पि.एस.)

- अक्षांश : ______
- देशान्तर : ______
- उचाइ : ______

२. प्लटको सामान्य जानकारी

एउटामा गोलो घेरा लगाउनु

वनको प्रकार :	प्राकृतिक / वृक्षारोपण
मोहडा :	N, S, E, W, NE, NW, SE, SW, Flat
माटोको प्रकार :	clayey, loam, sandy, boulder
आगलागी :	छ / छैन
डालेपात संकलनका संकेतहरु :	छ / छैन
चरीचरणको संकेतहरु :	छ / छैन
दाउरा संकलनका संकेतहरु :	छ / छैन
काठ संकलनका संकेतहरु :	छ / छैन
अतिक्रमण :	छ / छैन
वन्य जन्तु भएको संकेतहरु :	छ / छैन
पहिरो/भूक्षय :	छ / छैन

वनस्पतिको प्रकार :	
भिरालोपन :	औसत डिग्री
माटोको रङ :	
माटोको गहिराइ :	मीटर
रुखको छत्र ढकाइ :	%
झाडि प्रजातिको छत्र ढकाइ :	%
भुई ढकाइ :	%

अन्य विशेष जानकारी

जिल्ला : ________ स्ट्राटा : ________ प्लट संख्या : ________

३. नमुना प्लट भित्र नापजाँच गरिनु पर्ने भुँई घाँस, सोत्तर र माटो को लागि फारम

१. भुँई घाँस (Herbs and Grass)- ०.५६ मि. अर्धव्यास भएको गोलो प्लटमा जोख्ने (५ से.मि. व्यास भन्दा साना सबै बिरुवाहरु)

प्लट भरीको भुँईघाँसको जम्मा तौल (ग्राममा)	नमुना भुँईघाँसको तौल (ग्राममा)			नमुना राखेको प्याकेट नं.
ग्राम	ग्राम			
	थैला	कपडा	प्लाष्टीक	

२. सोत्तर (Litter) - ०.५६ मि. अर्धव्यास भएको गोलो प्लटमा जोख्ने

प्लट भरीको सोत्तरको जम्मा तौल (ग्राममा)	नमुना सोत्तरको तौल (ग्राममा)			नमुना राखेको प्याकेट नं.
ग्राम	ग्राम			
	थैला	कपडा	प्लाष्टीक	

३. माटो (Soil) १ मि अर्धव्यास भएको गोलो प्लटको केन्द्रबिन्दु वरीपरी संकलन गरेको माटो नमुना

० देखी १० से.मी.	० से.मी. – १० से.मी.	नमुना माटोको नं.
१० देखी २० से.मी.	२० से.मी.	नमुना माटोको नं.
२० देखी ३० से.मी.	३० से.मी.	नमुना माटोको नं.

संयुक्त नमुनाको (कार्बन मापनको लागी)

नमुना लिएको माटोको जम्मा तौल		
	ग्राम	
थैला	सेतो प्लाष्टीक	कालो प्लाष्टीक
नमुना माटोको संकेत नं.		

४. पुनरुत्पादन (१ से.मी. भन्दा कम व्यास भएको): १ मि. अर्धव्यास भएको गोलो प्लटमा गन्ने

सि. नं.	प्रजाति	जम्मा संख्या
1		
2		
3		
4		
5		
6		
7		

सि. नं.	प्रजाति	जम्मा संख्या
8		
9		
10		
11		
12		
13		
14		

५. लाथ्राहरुको मापन (१–५ से.मी. व्यास भएको): १ मि. अर्धव्यास भएको गोलो प्लटमा नाप्ने

सि. नं.	प्रजाति	व्यास (से.मी.)	व्यास नापेको स्थान: (छातिको उचाइ (१.३ मी) मा	व्यास नापेको स्थान: ३० से.मी. मा	कैफियत
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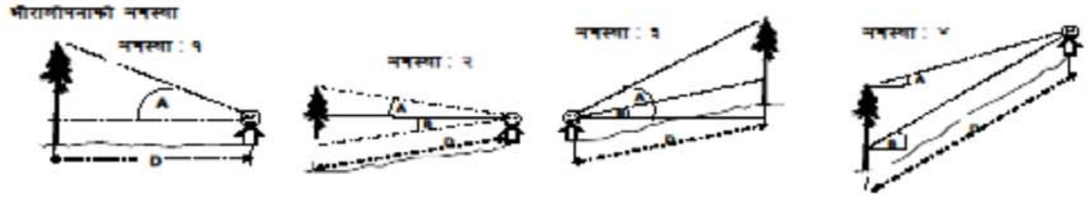
15		.			

७. ठूला रुखहरुको व्यास र उचाई मापन

जिल्ला : ______ स्ट्राटा : ______ प्लट संख्या : ______



सि. नं.	प्रजाति	व्यास (छातिको उचाइ (१.३ मी) मा, से.मी.)	रुखको फेद र टुप्पोको कोण (डिग्रिमा) टुप्पोको (A)	फेदको (B)	रुख सम्मको दुरी (मी.) (D)	जमिनको भिरालोपन अवस्था (माथिको चित्र अनुसार)	डिग्रि	रुखको उचाई (मी.)	रुखको अवस्था
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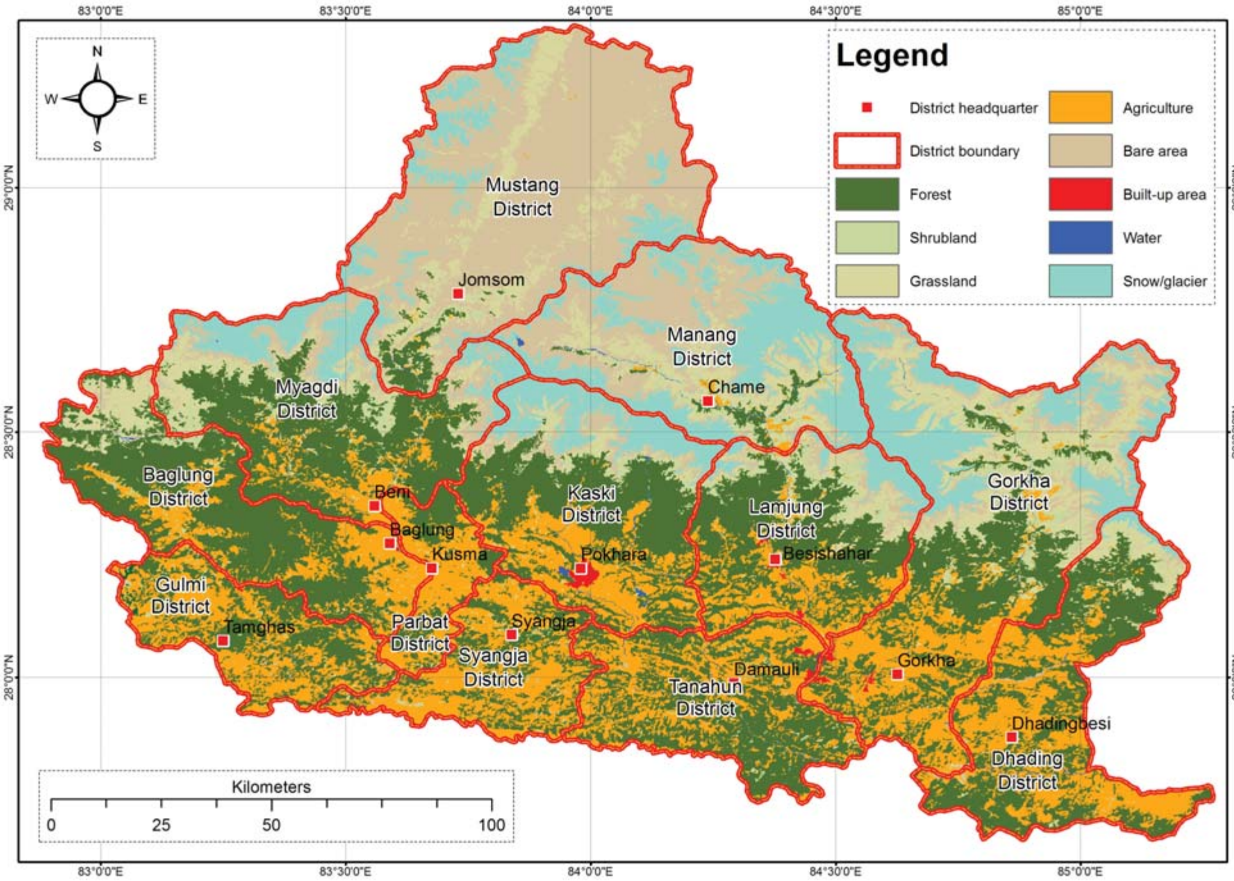
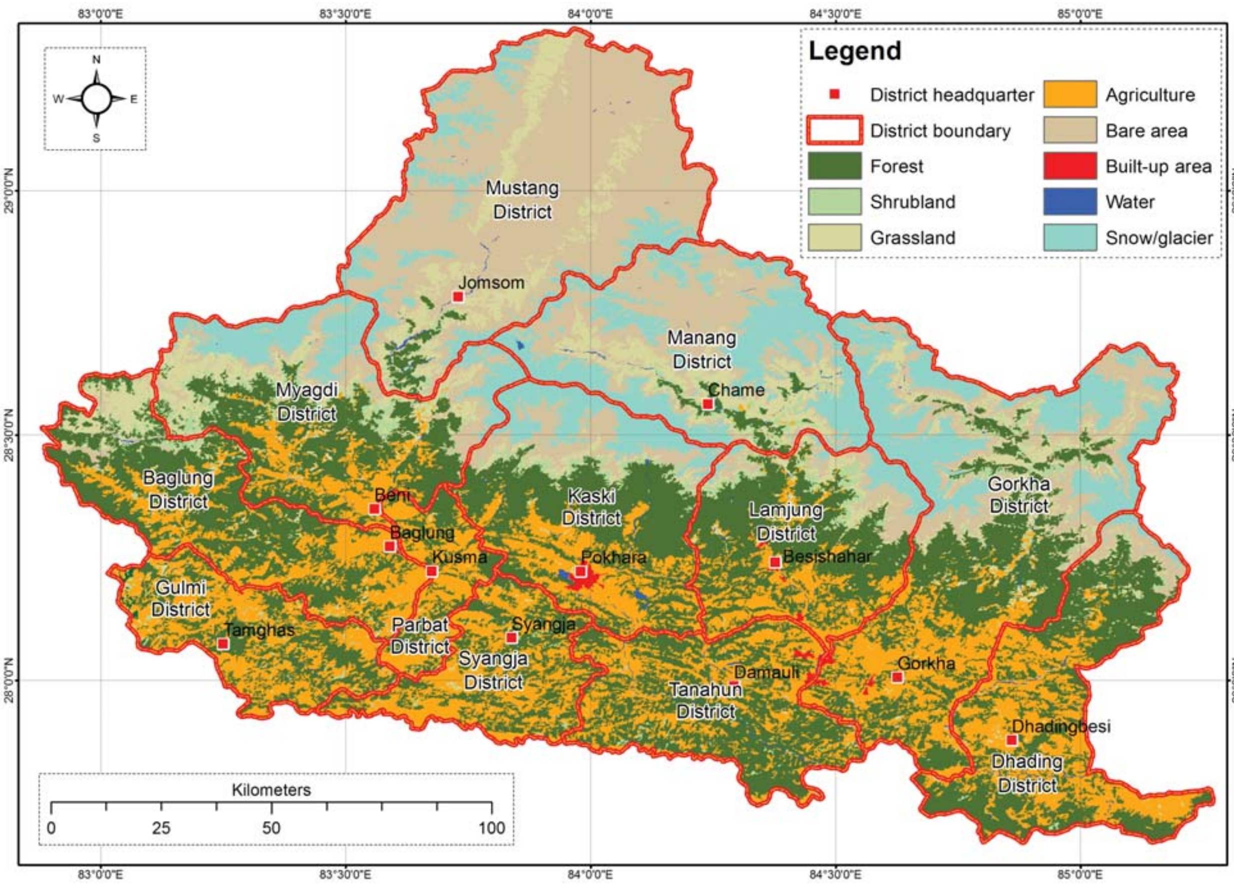
- भिरालोपन अनुसार १५.४५ मि. समतल बराबरको अर्धव्यास (७५० व.मी. क्षेत्रफल) भएको गोलो प्लटमा मापन कार्य गर्ने ।
- ५ से.मी. भन्दा बढि व्यास भएका सबै रुखहरुको नाप लिनु पर्ने ।

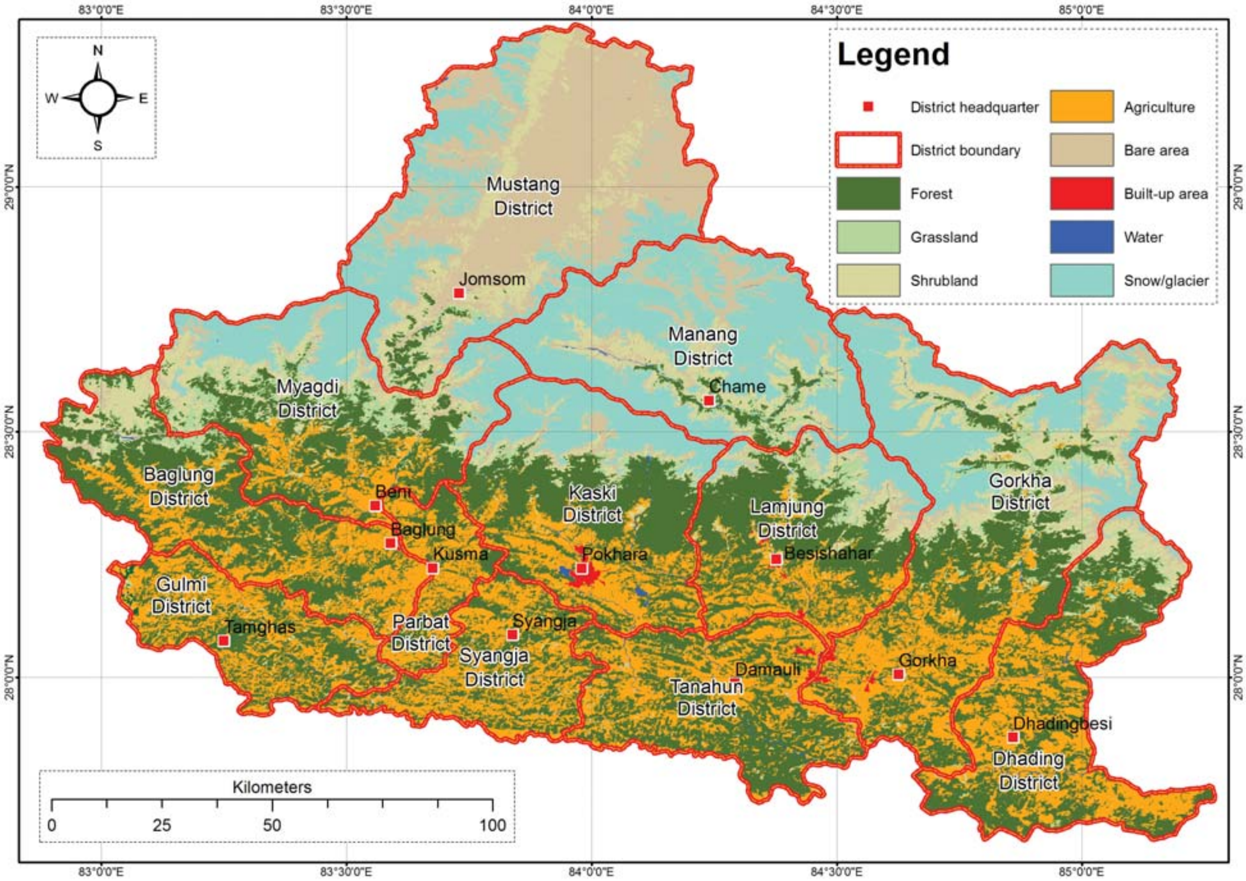
Annex 4: List of equipment's and their use

S.N.	Particulars	Purpose
1.	GPS	Boundary survey, stratification and locating plots
2.	Base map	Plot navigation
Permanent plot establishment		
3.	Rope	For plot boundary delineation
4.	Linear tape	For locating plot boundary and distance measurement
5.	Chalk	For marking the trees within the boundaries temporarily before permanent tagging and ensure that it is measured.
Leaf litters and herb/grasses collection		
6.	Plastic bags	White plastic bags to collect samples and big plastic bags to collect and weigh herbs, grasses and leaf litters
7.	Clothes bag for leaflets and twigs	Since, plastic bags may get tore herbs, grasses and leaf litters should be collected in clothes.
8.	Knife or sickle	For cutting herbs and grasses
9.	Weighing machine	For weighing herbs, grasses and leaf litters
10.	Scissors	For cutting herbs and grasses
Soil sample collection		
11.	Metal scale	For measuring soil depth
12.	Soil sample core	For collecting soil samples from various depths
13.	White clothes or masking tape	For tightening the soil core so that no soil comes out of the soil core
14.	Soil sample hammer	For bear down on the soil core while collecting sample
15.	Weighing machine	For weighing sample
16.	Kuto	For taking out soil core from soil depth
Height and diameter measurement		
17.	Linear tape	For measuring distance between tree and measurer
18.	Diameter tape	For measuring diameter of the tree at breast height
19.	Clinometer	For measuring the ground slope, top and bottom angle to the tree
20.	Vertex IV and Transponder	For measuring tree height and establishing circular plots without the use of tapes and clinometers.
21.	Callipers	Can be used instead of diameter tape to measure diameter of trees.

Annex 5: Land cover maps (1978,1990,2000 and 2010)






Legend
District headquarter
District boundary
Forest
Grassland
Shrubland
Agriculture
Bare area
Built-up area
Water
Snow/glacier
Kilometers
0 25 50 100
83°0'0"E
83°30'0"E
84°0'0"E
84°30'0"E
85°0'0"E
29°0'0"N
28°30'0"N
28°0'0"N
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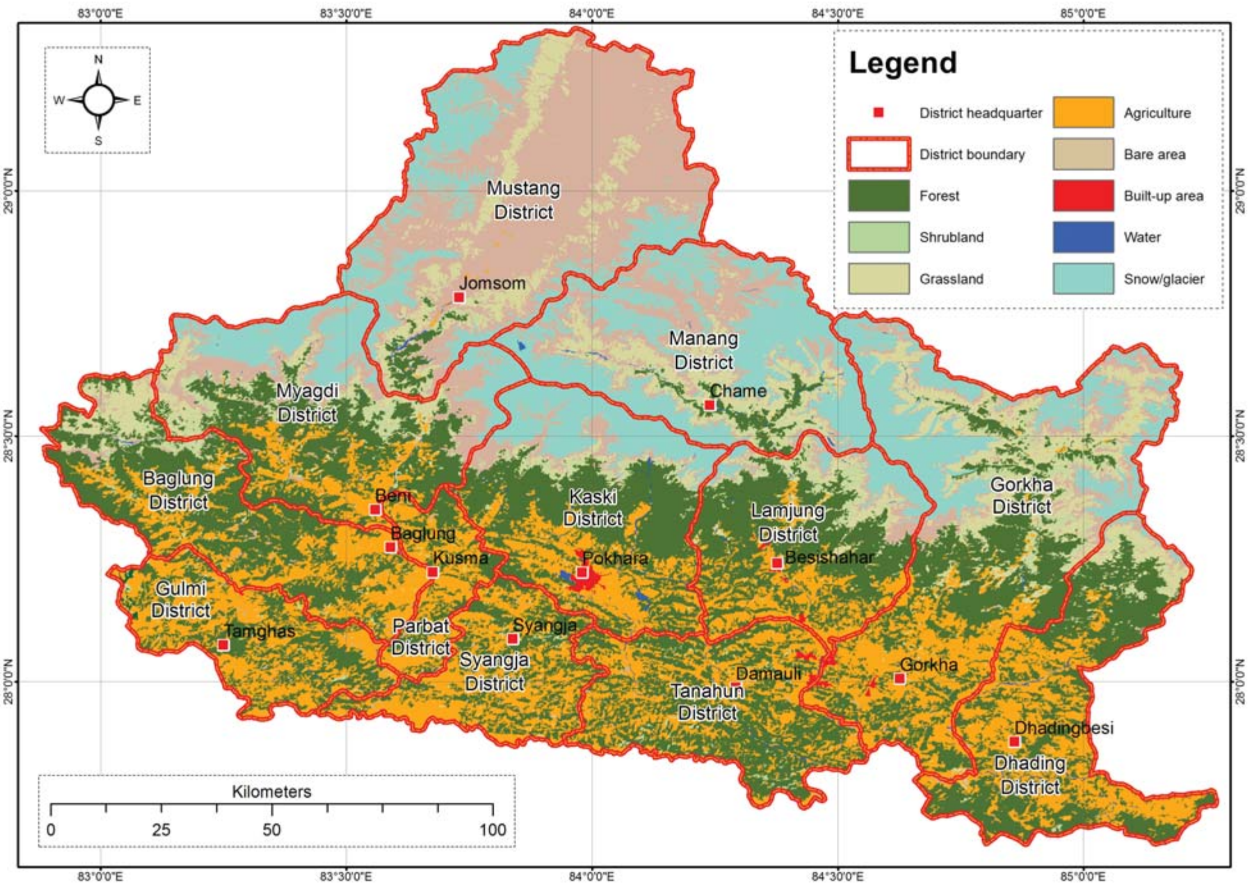
Mustang District
Jomsom
Manang District
Chame
Myagdi District
Baglung District
Beni
Baglung
Kusma
Kaski District
Pokhara
Lamjung District
Besishahar
Gorkha District
Gulmi District
Tamghas
Parbat District
Syangja
Syangja District
Damauli
Tanahun District
Gorkha
Dhadingbesi
Dhading District


Legend
District headquarter
District boundary
Forest
Shrubland
Grassland
Agriculture
Bare area
Built-up area
Water
Snow/glacier
Kilometers
0 25 50 100
83°0'0"E
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84°30'0"E
85°0'0"E
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Mustang District
Jomsom
Manang District
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Myagdi District
Baglung District
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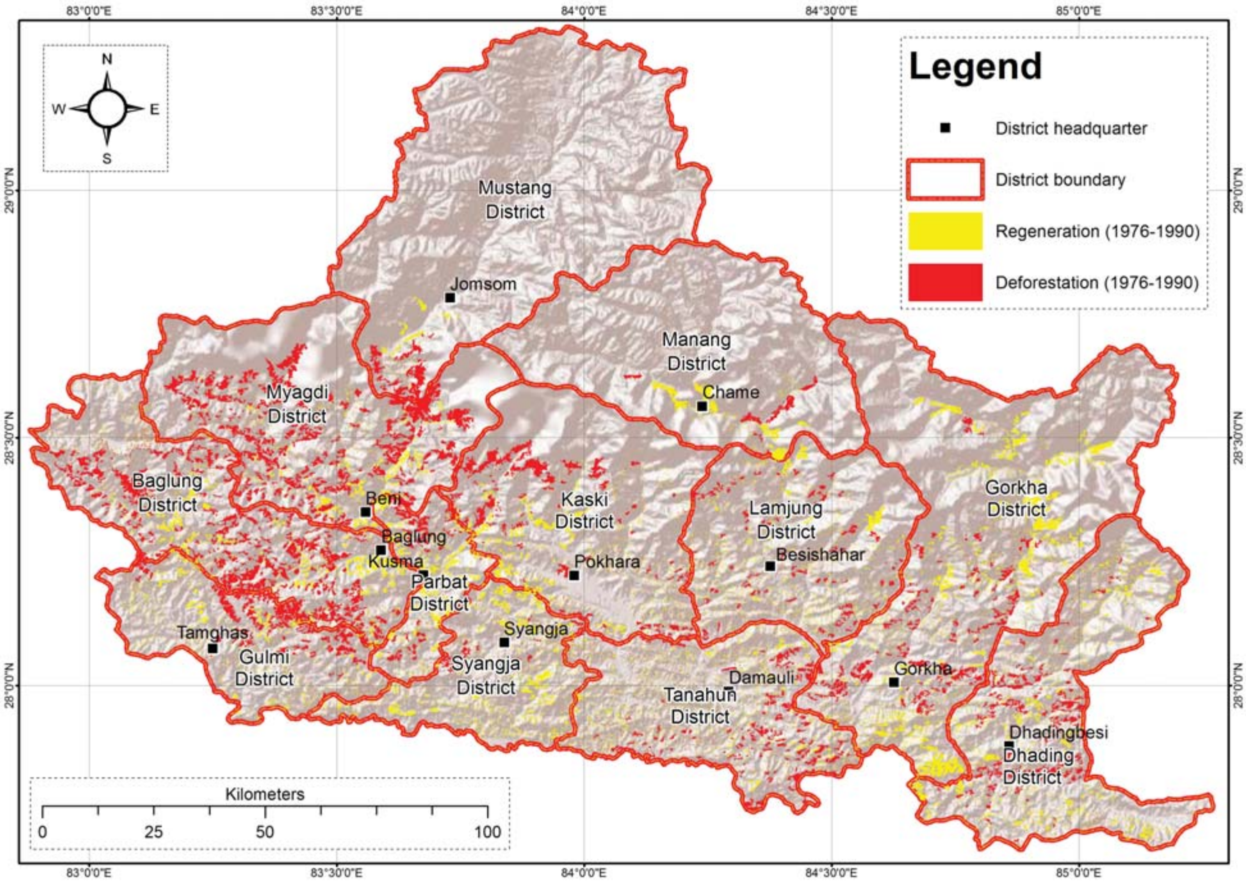
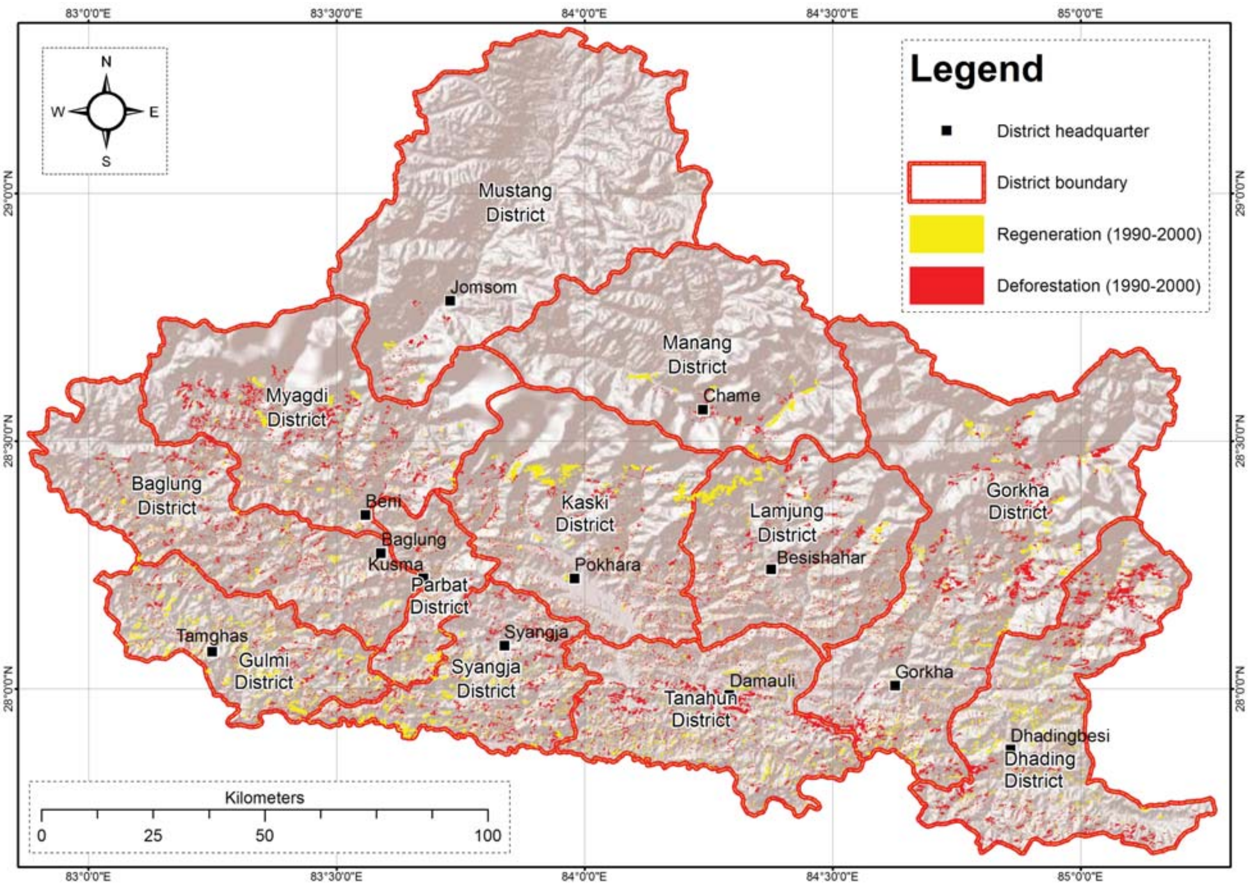
Baglung
Kusma
Kaski District
Pokhara
Lamjung District
Besishahar
Gorkha District
Gulmi District
Tamghas
Parbat District
Syangja
Syangja District
Damauli
Tanahun District
Gorkha
Dhadingbesi
Dhading District

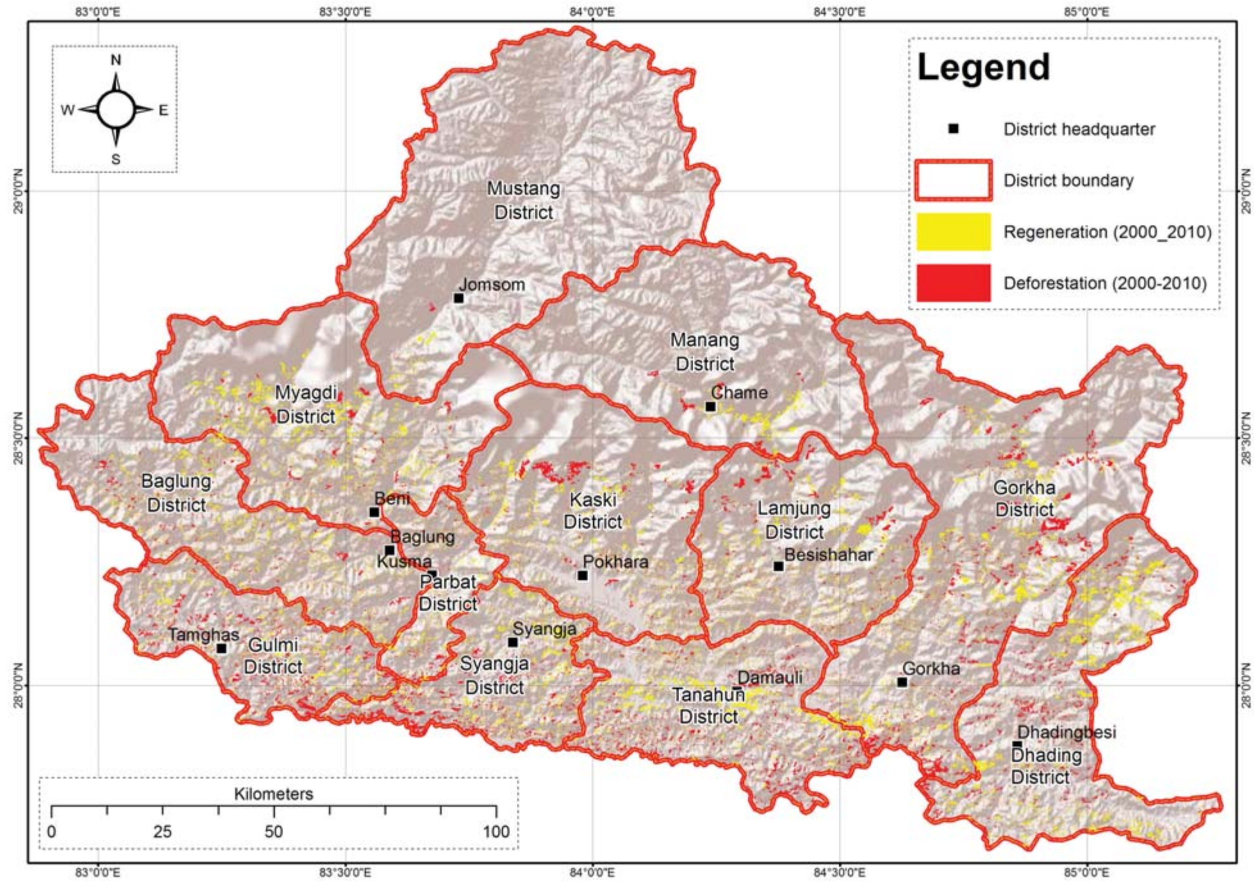
Annex 6: District level – Land cover statistics in CHAL

Classes	Year	Baglung	Dhading	Gorkha	Gulmi	Kaski	Lamjung	Manang	Mustang	Myagdi	Parbat	Syangja	Tanahun	Total
		Area (Km^2)												
Forest	1978	1040.1	957.2	927.8	488.6	914.4	853.7	65.3	105.7	894.5	205.6	405.1	874.6	7732.6
	1990	970.7	942.7	985.7	462.1	886.5	841.9	78.6	69.1	772.9	220.7	416.3	858.3	7505.5
	2000	944.4	906.0	958.3	495.6	888.5	835.0	93.6	67.2	719.7	228.3	429.0	825.6	7391.2
	2010	961.9	937.4	945.4	453.3	897.6	846.9	103.6	71.7	756.3	225.0	417.3	832.2	7448.7
Shrubland	1978	82.4	28.1	163.0	14.5	48.6	82.3	85.8	27.1	170.3	5.1	18.0	15.5	740.7
	1990	71.5	19.9	97.7	12.7	43.4	78.2	71.0	24.6	148.1	2.9	11.5	17.9	599.3
	2000	86.6	43.6	153.6	13.0	44.8	83.5	73.8	39.7	201.3	3.2	8.8	18.5	770.3
	2010	87.2	31.1	161.7	10.9	52.0	89.7	81.5	37.5	178.4	3.4	11.0	26.6	771.0
Grassland	1978	153.9	113.0	659.1	21.5	109.1	145.7	399.4	471.9	266.8	7.6	11.5	12.5	2372.2
	1990	173.0	66.8	318.7	15.7	71.7	118.1	377.6	455.1	318.6	5.4	12.8	10.1	1943.6
	2000	162.7	115.7	562.4	19.8	83.8	156.2	329.2	477.0	327.3	5.7	9.4	13.4	2262.6
	2010	143.4	119.3	628.4	14.8	63.3	132.7	387.9	447.3	175.3	4.8	5.5	8.3	2130.9
Agriculture	1978	497.7	755.0	670.9	563.1	439.6	349.9	32.5	5.5	261.5	320.5	586.2	631.4	5113.8
	1990	575.4	751.2	663.9	597.5	448.2	367.4	22.2	6.8	291.0	310.0	577.7	640.6	5251.7
	2000	602.9	790.1	704.7	556.4	451.3	357.0	17.5	7.3	280.0	299.6	570.2	665.6	5302.7
	2010	588.1	761.6	675.6	611.0	453.1	356.9	16.6	7.5	281.6	301.7	581.0	661.4	5296.2
Barren area	1978	52.6	21.1	389.8	15.5	136.8	91.5	869.5	2524.6	277.1	2.7	11.3	14.3	4406.7
	1990	35.7	92.5	653.7	13.4	227.1	137.6	875.3	2559.8	300.5	2.4	10.0	13.2	4921.3
	2000	27.0	28.1	265.8	15.8	97.4	72.1	367.3	2135.3	156.6	4.2	12.3	18.4	3200.3
	2010	45.2	31.1	401.4	11.6	129.1	89.3	663.9	2292.0	388.2	6.0	14.1	14.3	4086.3
Built-up area	1978	3.5	0.9	10.3	0.8	23.9	6.9	1.1	1.2	1.3	0.3	1.0	8.8	60.1
	1990	3.6	1.0	11.1	0.9	24.8	7.1	1.2	1.5	1.5	0.5	2.0	9.8	65.0
	2000	3.8	1.6	11.3	0.9	25.8	7.6	1.4	1.7	1.9	0.6	2.6	10.7	69.9
	2010	3.9	1.6	11.5	1.0	28.0	8.1	1.5	2.1	1.9	0.7	3.0	11.0	74.2
Water body	1978	4.5	10.2	9.4	3.0	17.4	4.9	8.7	1.3	4.8	0.3	5.0	14.8	84.4
	1990	4.6	14.4	10.1	4.6	20.2	5.4	9.6	10.1	3.8	0.2	7.7	22.3	113.0
	2000	5.4	11.4	10.2	5.4	19.0	5.2	8.6	4.8	5.0	0.4	5.8	19.7	101.0
	2010	4.7	16.1	10.2	4.4	21.8	4.1	11.0	7.4	4.8	0.4	6.0	18.3	109.2
Snow and glacier	1978	1.2	40.5	779.6		334.1	127.2	858.7	426.6	408.6				2976.6
	1990	1.4	37.5	869.0		302.2	106.3	885.4	437.1	448.6				3087.5
	2000	3.3	29.6	943.6		413.4	145.4	1429.5	831.1	593.2				4389.1
	2010	1.5	27.9	775.9		379.1	134.3	1054.9	698.5	498.5				3570.5

Annex 7: Forest cover change maps (1978-1990, 1990-2000 and 2000-2010)






Legend
District headquarter
District boundary
Regeneration (2000_2010)
Deforestation (2000-2010)
Mustang District
Jomsom
Manang District
Chame
Myagdi District
Baglung District
Beni
Baglung
Kusma
Parbat District
Kaski District
Pokhara
Lamjung District
Besishahar
Gorkha District
Gorkha
Tamghas
Gulmi District
Syangja
Syangja District
Damauli
Tanahun District
Dhadingbesi
Dhading District
Kilometers
0 25 50 100
N
S
E
W
83°0'0"E
83°30'0"E
84°0'0"E
84°30'0"E
85°0'0"E
29°0'0"N
28°30'0"N
28°0'0"N

Annex 8: List of tree species found in 12 CHAL districts

S.N.	Local name	Botanical name	Family
1	Aankhatare	*Trichilia connaroides* (Wight & Arn) Benfvelzen	Meliaceae
2	Amala	*Nephrolepis auriculata* (L.) K. Presl.	Nephrolepidaceae
3	Amba	*Psidium guajava* Linn.	Myrtaceae
4	Amili	*Tamarindus indica* Linn.	
5	Angere	*Lyonia ovalifolia* (Wall.) Drude	Ericaceae
6	Archal	*Antidesma acidum* Retz.	Euphorbiaceae
7	Ashare	*Lagerstroemia parviflora*	Lythraceae
8	Bakaino	*Melia azedarach* Linn.	Meliaceae
9	Bakhra Kane	*Oxyspora paniculata* (D. Don) DC.	Melastomataceae
10	Bakle	*Myrsine excelsa* D. Don	Myrsinaceae
11	Ban Aaru	*Prunus persica* (L.) Batsch	Rosaceae
12	Ban chuletro	*Brassiopsis hainla*	Araliaceae
13	Banjh	*Quercus lanata* Sm. Ba	Fabaceae
14	Banjh	*Quercus lanata* Sm.	Fabaceae
15	Barkamle	*Casearia graveolens* Var.	Flacourtiaceae
16	Bayar	*Zizyphus mauritiana* Lam.	Rhamnaceae
17	Berulo	*Ficus subincisa*	Moraceae
18	Bhakimlo	*Rhus chinensis* Mill.	Anacardiaceae
19	Bhalayo	*Rhus wallichii* Hook.f.	Anacardiaceae
20	Bhatmase	*Fleminigia congesta* Robox.	Fabaceae
21	Bhatte	*Flemingia semialata*	Fabaceae
22	Bhelar/	*Trewia ndiflora* Linn.	Euphorbiaceae
23	Bhimsen pati	*Rabdosia ternifolia* (D. Don) Hara.,	Labiatae
24	Bhojpatra	*Betula utilis* D. Don	Betulaceae
25	Bhokate	*Citrus maxima* (Burm. ex Rumph.) Merr.	Rutaceae
26	Bhote Pipal	*Populus ciliata* Wall.	Salicaceae
27	Bhuletro	*Butea minor* Buch.-Ham. ex Baker	Fabaceae
28	Mausure Katus	*Castanopsis tribuloides* (Sm.) A. DC.	Fagaceae
29	Bilaune	*Maesa chisia* Buch.- Ham.ex D. Don	Myrsinaceae
30	Boke Ghans	*Ageratum conyzoides* Linn.	Asteraceae
31	Botdhangero	*Lagerstroemia parviflora*	Lythraceae
32	Burans	*Rhododendron campanulatum*	Ericaceae
33	Chandan	*Pterocarpus santalinus*	Fabaceae
34	Chanp	*Michelia champaka* L.	Magnoliaceae
35	Chilaune	*Schima wallichii* (DC.) Korth.	Theaceae
36	Chimal	*Rhododendron campanulatum* D.Don	Ericaceae
37	Chiuri	*Madhuca longifolia* (Koeing) Macbride	Sapotaceae
38	Chuletro	*Brassiopsis hainla* Buch., Ham.	Araliaceae
39	Chutro	*Berberis aristata* DC.	Berberidaceae
40	Daar	*Boehmeria rugulosa* Wedd.	Urticaceae
41	Dabdabe	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae
42	Dhaire	*Woodfordia fruticosa* (L.) Kurz.	Lythraceae
44	Dhale Katus	*Castanopsis indica* (Roxb.) Miq.	Fabaceae
45	Dhaman	*Grewia optiva* J.R Drman.ex.Burret	Tiliaceae
46	Dhayaro	*Woodfordia fruticosa* (L.) Kurz.	Lythraceae
48	Dhupi salla	*Cryptomeria japonica* (L. f.) D. Don	Taxodiaceae
49	Dhursul	*Colebrookea oppositifolia* Sm.	Lamiaceae

S.N.	Local name	Botanical name	Family
50	Dudhilo	*Ficus neriifolia* Sm.	Moraceae
51	Dumri	*Ficus sarmentosa* Buch.-Ham. ex Sm.	Moraceae
52	Gayo	*Buchanania latifolia* Roxb.	Anacardiaceae
53	Gedilo	*Ficus subincisa* Buch.-Ham.ex SM.	Moraceae
54	Ghore	*Thamnocalams* sp.	Poaceae
55	Ghot Tapre	*Centella asiatica* (L.) Urb.	Apiaceae
56	Ghurmiso	*Leucosceptrum canum* Sm.	Lamiaceae
57	Githi	*Boehmeria rugulosa* Wedd.	Urticaceae
58	Gobre Salla	*Pinus wallichiana* A.B Jackson	Pinaceae
59	Gogane/Phalant	*Quercus lamellosa* J.E Sm.	Fagaceae
60	Gurans	*Rhodendron arboreum* L.	Ericaceae
61	Guyalo	*Callicarpa macrophylla* Vahl	Verbenaceae
62	Harro	*Terminalia chebula* Retz.	Combretaceae
63	Ipil Ipil	*Leucaena leucocephala* (Lam.) De Wit	Fabaceae
64	Jamane Mandro	*Mahonia nepaulensis* DC.	Berberidaceae
65	Jamun	*Syzygium jambos* (L.) Alston	Myrtaceae
66	Jhikune pat	*Euria acuminata* DC.	Theaceae
67	Jhigune	*Euria cerasifolia* (D.Don) Kobuski	Theaceae
68	Kafal	*Myrica esculenta* Bch.-Ham.ex d.Don	Myricaceae
69	Kangiyo	*Grevillia robusta* A.Cunn.ex R.Br.	Proteaceae
70	Kalikath	*Miliusa velutina* (Dunal) Hook. F.& Thoms	Annonaceae
71	Khamari	*Gamelia arborea* Roxb.	Verbenaceae
72	Karanga	*Caesalpinia decapetala* (Roth) Alston	Fabaceae
73	Kesar	*Mesua ferrea* L.	Clusiaceae
74	Kaulo	*Persea duthiei* (kingex Hook.f.) Kosterm	Lauraceae
75	Khair	*Acacia catechu* (L. f.) Willd.	Fabaceae
76	Khallu	*Diospyros malabarica* (Desr.) Kostel.	Ebenaceae
77	Khanyu	*Ficus semicordata* Buch.-Ham.ex Sm.	Moraceae
78	Khasru	*Quercus semicarpifolia* Sm.	Fagaceae
79	Khirro	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex D. Don	Apocynaceae
80	Kholme	*Symplocos racemosa* Roxb. var. racemosa	Symplocaceae
81	Khote Sallo	*Pinus roxburghii* Sarg.	Pinaceae
82	Kore/Tilkore	*Solena heterophylla* Lour.	Cucurbitaceae
83	Kumbo	*Careya herbacea* Roxb.	Lecythidaceae
84	Koiralo	*Bauhnia purpurea* L.	Caesalpiniaceae
85	Kutmero	*Litsea glutinosa* (Lour.) C.B.Rob.	Lauraceae
86	Kyamuna	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry	Myrtaceae
87	Kyamuno	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry	Myrtaceae
88	Lahare	*Jasminum mesney* Hance	Oleaceae
89	Lakuri	*Fraxinus floribunda* Wall.	Oleaceae
90	Lapsi	*Choerospondias axillaris* (Roxb.) B.L. Burtt&A.W. Hill	Anacardiaceae
91	Lati Mahuwa	*Madhuca latifolia* (Roxb.) Macbride	Sapotaceae
92	Latikath	*Cornus oblonga* (Wall.) Sojak	Cornaceae
93	Lokta	*Daphne bholua* Buch.-Ham. ex D. Don	Thymelaeceae
94	Loth Salla	*Taxs wallichiana* (Zucc.) Pilger	Taxaceae
95	Mal	*Macaranga denticulata* (Blume) Mull-Arg.	Euphorbiaceae
96	Mel/Mayal	*Pyrus pashia* Buch.-Ham.ex D.Don	Rosaceae
97	Mallato	*Macaranga pustulata*	Euphorbiaceae

S.N.	Local name	Botanical name	Family
98	Mango	*Mangifera indica* Linn.	Anacardiaceae
99	Masala	*Eucalyptus camaldulensis* Dehn.	Myrtaceae
100	Mahuwa	*Engelhardia spicata* Leschen. ex Blume	Juglandaceae
101	Musure Katus	*Castanopsis tribuloides* (Sm.) A. DC.	Fagaceae
102	Narkat	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae
103	Nibuwa	*Citrus limon* (L.) Burm.f.	Rutaceae
104	Nivaro	*Ficus auriculata* Lour.	Moraceae
105	Okhar	*Juglance regia* L.	Juglandaceae
106	Padke	*Albizia odoratissima* (L. f.) Benth.	Fabaceae
107	Pahele	*Litsea lancifolia* (Roxb. ex Nees) Hook. f.	Lauraceae
108	Paiyu	*Prunus cerasoides* D.Don	Rosaceae
109	Palash	*Butea monosperma* (Lam.) Kuntze	Fabaceae
110	Pinge	*Cinnamomum tamala* (Buch.-Ham.) Nees & Eberm.	Lauraceae
111	Pangra /pangra/ Karu/Kandar	*Aesculus indica* (Colebr.ex Cambess) Hook.	Hippocastanaceae
112	Pate salla	*Pinus patuula* Schiede and Deepe	Pinaceae
113	Patar	*Ficus rumphii* Blume.	Moraceae
114	Patle Katus	*Castanopsis lancifolia* (Kurz) Hickel & A. Camus	Fabaceae
115	Pwale/Punwale	*Ilex excelsa* (Wall.) Hook.f.	Aquifoliaceae
116	Phalaedo	*Erythrina stricta* Roxb.	Fabaceae
117	Phalame	*Mesua ferrea* L.	Clusiaceae
118	Phale	*Litsea oblonga* (Nees) Hook. f.	Lauraceae
119	Phalat	*Quercus lanata* Sm.	Fabaceae
120	Phaledo	*Erythrina stricta* Roxb.	Fabaceae
121	Phirphire	*Acer oblongum* Wall. ex DC.	Aceraceae
122	Phusre	*Grewia subinaqalis* DC.	Tiliaceae
123	Pipal	*Ficus religiosa* L.	Moraceae
124	Rakchan	*Daphniphyllum himalense* (Benth.) Mull.-Arg.	Daphniphyllaceae
125	Rato Kaiyo	*Wendlandia exserta* (Roxb.) DC.	Rubiaceae
126	Ratpate	*Ajuga bracteosa* Wall ex. Benth.	Lamiaceae
127	Ramphal	*Annona reticulata* L.	Annonaceae
128	Saj	*Terminalia alata* Heyne ex Roth	Combretaceae
129	Sal	*Shorea robusta* Gaertn.	Dipterocarpaceae
130	Salla	*Pinus roxburghii* (L. f.) D. Don	Pinaceae
131	Sanan	*Celtis australis* L.	Ulmaceae
132	Simal	*Morus australis* Poir.	Moraceae
133	Sindure	*Mallotus philippensis* (Lam.) Mull.- Arg.	Euphorbiaceae
134	Sinkauli	*Cinnamomum bejolghota* (Buch.- Ham.) Sweet	Lauraceae
135	Sirish	*Albizia odoratissima* (L. f.) Benth.	Fabaceae
136	Sissoo	*Dalbergia sissoo* Roxb. ex DC.	Fabaceae
137	Talispatra	*Abies spectabilis* (D.Don) Mirb.	Pinaceae
138	Tanki	*Bauhinia purpurea* L.	Fabaceae
139	Tejpat	*Cinnamomum tamala* (Buch.-Ham.) Nees & Eberm.	Lauraceae
140	Thingure Salla	*Tsuga dumosa* (D.Don) Eichler	Pinaceae
141	Teju/Tendu	*Diospyros tomentosa* Roxb.	Ebenaceae
142	Tilke	*Wendlandia coriacea*	Rbiaceae
143	Timur	*Zanthoxylum armatum* DC.	Rutaceae
144	Tuni	*Toona ciliata* M. Roem.	Meliaceae
145	Utis	*Alnus neplensis* D. Don.	Betulaceae

Annex 9: List of shrubs species found in forest strata of CHAL

S.N.	Local name	Botanical name	Family
1	Aaiselu	*Rubus paniculatus* Smith	Rosaceae
2	Allo	*Girardinia diversifolia* (Link) Friis	Urticaceae
3	Amala Jhar	*Cassia mimosoides* Linn.	Fabaceae
4	Ambar, Dadmeri	*Ammannia baccifera* Linn.	Lythraceae
5	Archal	*Antidesma acidum* Retz.	Euphorbiaceae
6	Aule Bayar	*Zizyphus oenoplia* (L.) Mill.	Rhamnaceae
7	Bajra Danti	*Potentilla fulgens* Wall. ex Hook	Rosaceae
8	Bakalpate	*Viburnum continifolium* D.Don.	Sambucaceae
9	Bakhri Ghans	*Brassaiopsis hainla* (Buch.-Ham. Ex D.Don) Seem	Araliaceae
10	Bakle	*Clerodendrum viscosum* Vent. f.rubrum Moldenke	Verbenaceae
11	Ban Kapas	*Thespesia lampas* (Cav.) Dalz. & Gibs.	Malvaceae
12	Bayere	*Zizyphus oenoplia* (L.) Mill.	Rhamnaceae
13	Bhatte/Bhatmase	*Flemingia congesta* Roxb. ex W. T. Aiton.	Fabaceae
14	Bhote Dakhh	*Ficus carica* L.	Moraceae
15	Bhuletro	*Butea minor* Buch.-Ham. ex Baker	Fabaceae
16	Bilaune	*Maesa chisia* Buch.- Ham.ex D. Don	Myrsinaceae
17	Chaite	*Cassia floribunda* Cav.	Fabaceae
18	Chakudi	*Cassia occidentalis* L.	Fabaceae
19	Chiple	*Gonostegia pentandra* (Roxb.) Miq.	Urticaceae
20	Chulesi (rato)	*Osbeckia rostrata* D.Don	Melastomataceae
21	Chutro	*Berberis aristata* DC.	Berberidaceae
22	Daar	*Boehmeria rugulosa* Wedd.	Urticaceae
23	Damaigiri	*Dicliptera bupleuroides* Nees	Acanthaceae
24	Dar Tusare	*Debregeasia salicifolia* (D. Don) Rendle	Urticaceae
25	Dhar	*Boehsmeria rugulosa* Wedd.	Urticaceae
26	Dhayaro	*Woodfordia fruticosa* (L.) Kurz	Lythraceae
27	Dhobini	*Mussaenda roxburghii* Hook.f.	Rubiaceae
28	Dhursil	*Colebrookea oppositifolia* Sm.	Labiatae
29	Dudh khirro	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don	Apocynaceae
30	Gaujo	*Millettia extensa* (Benth.) Baker	Fabaceae
31	Ghyano	*Inula cappa* (Buch.-Ham. ex D.Don)DC	Asteraceae
32	Ginneri	*Premna barbata* Wall. var. barbata	Verbenaceae
33	Gonjo, Gauj	*Millettia extensa* (Benth.) Baker	Fabaceae
34	Goru Ainselu	*Rubus rugosus* Smith	Rosaceae
35	Gullar	*Ficus pubigera* (Wall. ex Miq.) Brandis	Moraceae
36	Guyelo	*Callicarpa arborea* Roxb	Verbenacerae
37	Jhigane	*Eurya acuminata* DC.	Theaceae
38	Kade	*Caesalpinia bonduc* (L.) Roxb.	Fabaceae
39	Kalikath	*Miliusa velutina* (Dunal) Hook. f.& Thoms.	Annonaceae
40	Kamle	*Pilea symmeria* Wedd.	Urticaceae
41	Kandil	*Flacourtia indica* (Burm. f.) Merr.	Flacourtiaceae
42	Kanike Phool	*Sambucus canadensis* L.	Sambucaceae
43	Kanthakari	*Solanum xanthocarpim* Schrad. & H. Wendl.	Solanaceae
44	Ketuki	*Yucca gloriosa* L.	Agavaceae
45	Khade, Aireli kanda	*Caesalpinia decapetala* (Roth.) Alston	Fabaceae

S.N.	Local name	Botanical name	Family
46	Khareto	*Phyllanthus parvifolius* Buch.- Ham.ex D.Don	Euphorbiaceae
47	Khareto	*Hypericum uralum* Buch.-Ham. ex D.Don	Clusiaceae
48	Kimbu	*Morus nigra* L.	Moraceae
49	Kukurdaino	*Smilax aspera* L.	Liliaceae
50	Kuri jhar	*Lantana camara* Linn.	Verbenaceae
51	Kurilo	*Asparagus racemosus* (Wild) Oberm	Liliaceae
52	Latikath	*Cornus oblonga* (Wall.) Sojak	Cornaceae
53	Liso	*Scurrula parasitica* Linn.	Loranthaceae
54	Lokta	*Daphne bholua* Buch.-Ham. ex D. Don	Thymelaeaceae.
55	Machaino	*Gaultheria procumbens* Linn.	Ericaceae
56	Malayo	*Kalanchoe pinnata* (Lam.)	Crassulaceae
57	Malkagunu	*Celastrus paniculatus* Willd.	Celastraceae
58	Musli	*Murdannia scapiflora* (Roxb.) Royle	Commelinaceae
59	Naeer	*Indigofera atropurpurea* Buch.-Ham. Ex Hornem.	Fabaceae
60	Nigale Gava	*Murdannia japonica* (Thunb.) Faden	Commelinaceae
61	Nigalo	*Arundinaria intermedi* Michx.	Poaceae
62	Nilkanda	*Duranta repens* Linn.	Verbenaceae
63	Odale	*Abelmoschus manihot* (L.) Moench.	Malvaceae
64	Pahele	*Litsea lancifolia* (Roxb. ex Nees) Hook. f.	Lauraceae
65	Patuwa	*Melochia corchorifolia* Linn.	Sterculiaceae
66	Phalame kanda	*Homalium napaulense* (DC.) Benth.	Flacourtiaceae
67	Phirphere ghas	*Hydrangea robusta* Hook. f. & Thomson	Hydrangeaceae
68	Presni Pann	*Desmodium gangeticum* (L.) DC.	Fabaceae
69	Pyauli	*Reinwardtia indica* Dumort.	Linaceae
70	Rato Chulesi	*Osbeckia rostrata* D.Don	Melastomataceae
71	Rato kaiyo	*Wendlandia exserta* (Roxb.) DC.	Rubiaceae
72	Rudilo	*Pogostemon benghalensis* (Burm.f.) Kuntze	Lamiceae
73	Seto Chutro	*Brassaiopsis hainla* (Buch.-Ham. ex D.Don)	Araliaceae
74	Settee Kath	*Myrsine capitellata* Wall.	Myrsinaceae
75	Sidure, Chuwa	*Osbeckia nepalensis* Hook.	Melastomataceae
76	Simali	*Vitex negundo* Linn.	Verbenaceae
77	Sinkauli	*Cinnamomum bejolghota* (Buch.- Ham.)	Lauraceae
78	Siris kalao	*Alblzla lebbeck* (L.) Benth.	Mimosaceae
79	Sisno	*Urtica dioca* Linn.	Urticaceae
80	Tanki	*Bauhinia malabarica* Roxb.	Fabaceae
81	Tapre	*Cassia tora*	Leguminosae
82	Thulo Bansapti	*Flemingia macrophylla* (Willd)	Fabaceae
83	Thulo Bihi,	*Solanum torvum* Swartz	Solanaceae
84	Thulo kuro	*Wrightia arborea* (Dennst.) Mabberly	Apocynaceae
85	Timur	*Zanthoxylum armatum* DC.	Rutaceae

Annex 10: Species parameters details used to estimate sapling biomass (Tamrakar, 2000)

Scientific name	Local name	Intercept (a)	Slope (b)	R square
Alnus neplensis	Utis	-2.348	2.102	0.978
Casearia graveolens	Barkamle	-1.627	1.520	0.990
Castanopsis indica	Katus	-0.710	1.720	0.970
Engelhardia spicata	Mahuwa	-2.142	1.938	0.987
Eurya acuminate	Jhigune	-1.743	1.797	0.981
Ficus neriifolia	Dudilo	-0.986	1.750	-
Ficus semicordata	Khanyo	-1.370	2.010	0.940
Fraxinus floribunda	Lakuri	-2.130	2.082	0.971
Litsea monopetala	Kutmero	-1.880	2.260	0.940
Lyonia ovalifolia	Angari	-2.833	2.010	0.990
Maesa macrophylla	Bhokate	-1.769	1.650	0.766
Melastoma melabathricum	Chulese	3.670	1.050	0.980
Myrica esculenta	Kafal	-2.535	1.403	0.848
Myrsine capitellata	Setokath	-1.859	1.932	0.979
Phyllanthus embilica	Amala	-2.046	1.889	0.968
Pinus roxburghii	Khote sallo	-3.985	2.744	0.990
Pinus wallichiana	Gobre sallo	-1.816	1.816	0.990
Pyrus pahia	Mayal	-1.863	1.814	0.953
Quercus spp.	Baj	-0.532	0.988	0.786
Quercus spp.	Khasru	2.763	1.166	0.999
Rhododendron spp.	Laligurans	-2.533	1.393	0.698
Rhus wallichii	Bhalayo	-1.954	1.899	0.956
Schima wallichii	Chilaune	-2.220	2.520	0.980
Shorea robusta	Sal	-2.608	2.996	0.982
Wendlandia coriacea	Tilke	-1.280	1.432	0.999
all other species	Mixed species	-0.280	1.510	0.930

Annex 11: Details of outlier trees in different strata

Measurement year	District	Strata	Plot number	Species	DBH	Height
2013	Myagdi	Dense needle-leaf	30	Loth Salla	120.3	34.5
2013	Myagdi	Dense needle-leaf	30	Loth Salla	109.2	32.2
2013	Myagdi	Dense needle-leaf	30	Loth Salla	105.2	33.3
2013	Myagdi	Dense needle-leaf	30	Loth Salla	108.1	31.0
2013	Manang	Dense needle-leaf	12	Gobre Salla	49.0	20.7
2013	Manang	Dense needle-leaf	12	Gobre Salla	46.8	25.5
2013	Manang	Dense needle-leaf	12	Dhupi salla	54.8	20.8
2013	Manang	Dense needle-leaf	12	Loth Salla	42.5	13.8
2013	Manang	Dense needle-leaf	12	Loth Salla	40.0	14.2

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