TERAI FORESTS OF NEPAL

2024

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As a continuation of forest resource assessment (FRA) after 2015, the Government of Nepal initiated the remeasurement of FRA permanent sample plots in 2016. Furthermore, additional plots were established and measured following the FRA protocols to generate reliable results at the sub-national level.

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Yam Prasad Pokharel
Director General

Abbreviations

AGB	Aboveground Biomass
BGB	Below Ground Biomass
C	Carbon
CCSP	Concentric Circular Sample Plot
CF	Community Forest
DBH	Diameter at Breast Height (1.3 m)
DFRS	Department of Forest Research and Survey
DNPWC	Department of National Parks and Wildlife Conservation
FRA	Forest Resource Assessment
FRTC	Forest Research and Training Centre
GoN	Government of Nepal
KS	Khair-Sissoo
LRMP	Land Resources Mapping Project
MFSC	Ministry of Forests and Soil Conservation
NLCMS	National Land Cover Monitoring System
NTFPs	Non Timber Forest Products
OC	Organic Carbon
OL	Other Land
OWL	Other Wooded Land
PA	Protected Area
PSPs	Permanent Sample Plots
RS	Remote Sensing
SK	Sisoo-Khair
SOC	Soil Organic Carbon
SOP	Standard Operating Procedure
STMH	Sal-Terai Mixed Hardwood
SVWB	Stem Volume Without Bark
Tg	Teragram (1 Tg = $1X10^{12}$ g)
TMH	Terai Mixed Hardwood

Glossary

Aboveground biomass	Aboveground biomass refers to the biomass of trees and saplings (≥5cm DBH) above the soil. It includes deadwood but not stumps.
Belowground biomass	The biomass of trees and saplings (≥5cm DBH) contained within live roots and stumps.
Biomass	The biological material derived from living or recently living organisms. It includes both the above and belowground biomass of trees and saplings.
Broken tree	A tree of which the top or trunk has been cut or broken.
Bulk density	Soil mass per unit volume expressed in g/cm^3.
Canopy	The cover of branches and foliage formed by tree crowns.
Canopy cover/Closure	The percentage of ground covered by the vertical projection of the foliage of plants.
Carbon pool	Major components (Aboveground, belowground, and soil carbon) of carbon per unit area.
Co-dominant	A tree with a medium-sized crown at the level of the general canopy, which receives full light from above and at least from one side.
Cull tree	A malformed tree that yields no merchantable logs.
Dead unusable	A dead tree that cannot be used, even as firewood.
Dead usable	A dead tree that can be used as firewood or for another purpose.
Debris	Fallen dead trees and the remains of large branches (<10 cm diameter) on the forest floor
Dominant	A tree whose crown is larger than average and lies at or above the level of the general canopy and receives full light from above and from more than one side.
Dominant species	Species that dominate (comprise > 60% of the basal area) an ecological community (e.g. forest).
Forest	An area of land at least 0.5 ha and a minimum width/length of 20 m with a tree crown cover of more than 10% and tree heights of 5 m at maturity.
Growing stock	The sum of all trees by number or volume or biomass growing within a unit area.
High-quality sound tree	Live tree which will yield saw logs at least 6 m long at present or in the future.
Intermediate	A tree whose crown is smaller than average reaches the general level of the canopy but not above it and receives some direct light from above but little, if any, from the side.
Land cover	The physical material covering the surface of the earth.
Litter	Dead plant materials such as leaves, bark, needles, and twigs that have fallen to the ground.
Non Timber Forest Products	Forest products other than timber.
Other Land	All land that is not classified as Forest or Other Wooded Land.

Other Wooded Land (OWL)	Land not classified as forest spanning more than 0.5 ha, having at least 20 m width, and with a canopy cover of trees between 5% and 10%; trees should be higher than 5 m or able to reach 5 m *in situ*. or The canopy cover of trees less than 5% but the combined cover of shrubs, bushes and trees more than 10%, including the area of shrubs and bushes where no trees are present.
Precision	Refers to the size of deviations in estimating a population parameter in the repeated application of a sampling procedure. Standard errors and confidence limits are commonly quoted to quantify precision.
Remote Sensing (RS)	Data acquisition of land surface characteristics, such as total forest area, forest type, canopy cover and height, from sensors aboard aircraft or space-based platforms.
Sal Forest	A forest in which Sal (*Shorea robusta*) comprises more than 60% of the basal area.
Sal Terai mixed hardwood forest (STMH)	A forest in which Sal comprises 33-60% of the basal area and other associated species are present.
Shrub	An area occupied by woody perennial plants, generally 0.5-5.0 m at maturity and often without definite stems or crowns.
Sound Tree	A live tree not qualified as class 1 but with at least one 3 m saw log or two 1.8 m saw logs.
Stump	The remnant of a cut or fallen tree.
Suppressed	A tree with a smaller crown than normal for a tree of its age and size. It receives little or no direct sunlight and shows signs of retarded growth resulting from competition with dominant trees.
Terai Mixed Hardwood (TMH)	A forest whose composition in the canopy layer is so mixed that none of the species has over 60% basal area.

Main Results

Forest cover

- Forest and Other Wooded Land (OWL) cover 19.43% (392,240 ha) and 0.86% (17,338 ha), respectively, of the total area of the Terai physiographic region (2,018,950 ha). Thus, forest and OWL together cover 20.29% of the total area in the region.

Growing Stock

- The Terai forest contain a total of 241.57 million (615.87 per ha) live stems (≥ 5cm DBH). The number of standing dead stems (≥ 5cm DBH) was 3.81 million (9.72 per ha).
- The stem volume for live trees in the Terai forest is 78.78 million m^3 (200.86 m^3/ha).
- The main tree species in terms of proportion of stem volume are Sal (*Shorea robusta*) with 99.8 m^3/ha, followed by Asna (*Terminalia alata*) with 26.2 m^3/ha.
- The timber volumes without bark up to 10 cm top and up to 20 cm top diameters in the Terai forest are 148.4 m^3/ha and 125.9 m^3/ha respectively.
- The Terai forest contained 303.32 t/ha of air-dry biomass, equivalent to 275.72 t/ha of oven-dry biomass.

Carbon stock

- The total carbon in the soil component is 18.58 tg (47.38 t/ha).
- The total carbon in the litter and debris component is 0.13 tg (0.35 t/ha).
- The carbon stock of tree component in the Terai forest is 50.83 tg (129.60 t/ha).
- The total carbon stock in the three major carbon pools of Terai forests is 69.54 tg (177.33 t/ha)

Disturbances

- Livestock grazing, tree cutting, and forest fire are the top three disturbances in the Terai forests.

Executive Summary

This report presents the results of a forest resource assessment carried out in the Terai physiographic region of Nepal between 2016 and 2018. The forest inventory was conducted from a total of 367 sample plots. Among those, 171 plots (in 55 clusters) were the permanent sample plots (PSPs) established during the Forest Resource Assessment (FRA) 2010/11, which were remeasured in 2016. The remaining 196 plots (in 55 clusters) were newly established and measured in 2018. Forest-cover maps were derived from the annual land cover maps prepared using National Land Cover Monitoring System (NLCMS) by Forest Research and Training Center (FRTC). The report mainly consists of information on forest cover, growing stock, carbon stock, and disturbances.

The forest cover mapping shows that out of a total of 2,018,950 ha of land in the Terai physiographic region, 'forest' and 'other wooded land (OWL)' covered 19.43% (392,240 ha) and 0.86% (17,338 ha), respectively. Thus, forest and OWL together covered 20.29% of the total area in the region.

The assessment reveals that the Terai forest contained a total of 241.57 million (615.87 per ha) live stems (≥ 5cm DBH). Similarly, the number of standing dead stems (≥ 5cm DBH) is 3.81 million (9.72 per ha). The stem volume in the Terai forest is 200.86 m^3 per hectare. The main tree species in terms of proportion of stem volume are Sal (*Shorea robusta*) with 99.8 m^3per hectare, followed by Asna (*Terminalia alata*) with 26.2 m^3per hectare. The timber volumes without bark up to 10 cm top and up to 20 cm top diameters are 148.4 m^3per hectare and 125.9 m^3 per hectare respectively.

The Terai forests contain 303.32 tons per hectare of air-dry biomass, equivalent to 275.72 tons per hectare of oven-dry biomass. Similarly, the total carbon stock in the three major carbon pools of Terai forests is 69.54 tg (177.33 t/ha). During the assessment, livestock grazing, tree cutting, and forest fire were the top three disturbances in the Terai forests.

Table of Contents

List of Figures

List of Tables

List of Equations

CHAPTER 1: INTRODUCTION

1.1. Introduction

The Forest Resource Assessment (FRA) Nepal Project (2010-2014) conducted a comprehensive assessment of the Terai forests between 2010 and 2012 (DFRS, 2014). The project had established 171 permanent sample plots (PSPs) in 55 clusters in the Terai forests for the periodic measurement of various forest parameters. These PSPs were measured in 2016. An additional 196 plots in 55 clusters were established to enhance the reliability of the forest inventory and were measured in 2018. This report presents 1) the Terai forest statistics based on the measurement of a total of 367 plots (171 PSPs plus 196 additional plots) between 2016 and 2018, and 2) the area statistics of the Terai forests based on the National Land Cover Monitoring System (FRTC, 2022).

1.2. The Environment of the Terai Forests

The term "Terai" refers to the Terai Physiographic Region of Nepal. It occupies 2,016,998 ha[1] of the total land area of the country. In terms of geomorphology, it consists of gently sloping recent and post-Pleistocene alluvial deposits, which form a piedmont plain south of the Himalayan. It is bordered by the Indian Gangetic plain in the south and the Churia Physiographic Region in the north (Figure 1). It extends from 80˚ 4' 30" to 88˚ 10' 19" east longitudes and 26˚21' 53" to 29˚ 7' 43" north latitudes. Its elevation varies from 63 m to 330 m above mean sea level and is sloped gently at 2-10 m per kilometre (LRMP, 1986).

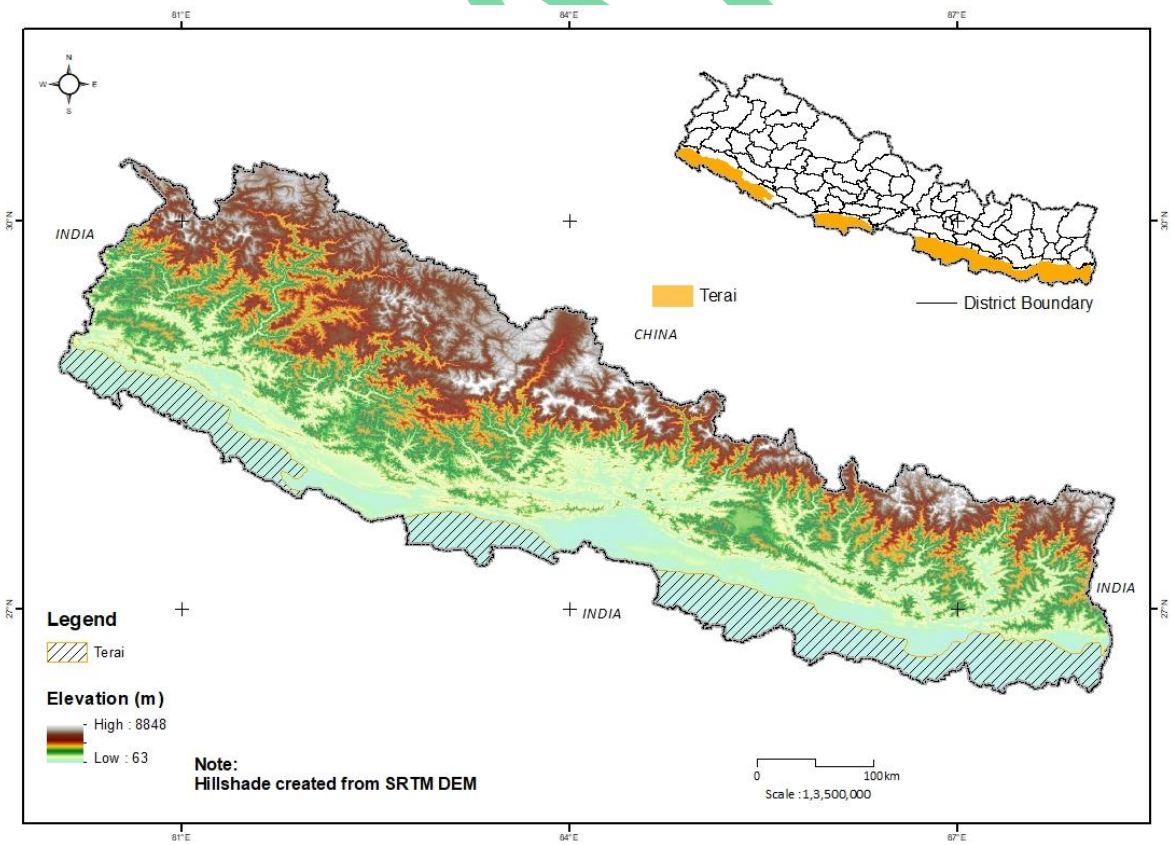

Figure 1: The spatial extent of the Terai in Nepal

[1] The official area statistics of the Terai Physiographic Region is 2,011,300 ha (Survey Department, 2001).

The Terai is divided into three subzones: the Bhabar, the Terai and the Southern Terai (Jackson, 1994). The Bhabar is a narrow stretch of recent alluvial and colluvial fan deposits at the foot of the Churia Hills; it consists of thick deposits of gravel, pebbles and boulders mixed with sand and silt. The alluvial and colluvial fans in the Bhabar coalesce into piedmont slopes and merge with the main Terai in the south, formed by sediments deposited by braided rivers. The Terai is the area where the water, which has drained into the gravels of the Bhabar, reappears again at the surface, whereas the Southern Terai is an extension of the Gangetic Plains.

Soils

Most soils in the Terai are alluvial deposits. Alluvium is unconsolidated material deposited by rivers. The nature of the alluvium depends on the parent materials from which it has been derived so that it may vary in texture from sand to clay (Jackson, 1994). The soils in the Bhabar, in contrast, generally consist of coarse sand, gravel and boulders. According to ISRIC (2009), Terai soils can be classified as i) Calcaric Fluvisol, ii) Gleysols, and iii) Phaeozems. Calcaric Fluvisol is found near rivers, and Gleysols are found in areas with permanent and temporary wetness near the surface. Phaeozems are thick, dark topsoils rich in organic matter and show evidence of the removal of carbonates. They are loamy textured, dark brown, calcareous and drought-prone soils.

Climate

The Terai is located in a sub-tropical climatic zone characterised by hot and humid summers, intense monsoon rain, and dry winters. The maximum and minimum monthly mean temperatures are 35-40 °C (in April/May) and 14-16 °C (in January), respectively (Jackson, 1994). The mean annual temperature increases across the Terai at 0.029°C/year in the Far-West and 0.049°C/year in the East and Mid-West. All four seasons are also warming up (Jones *et al.,* 2004).

The total annual precipitation varies from 2,680 mm in the east to 1,138 mm in the west, and the mean monthly precipitation ranges from 8 mm in November to 535 mm in July[2]. While 80% of the total rainfall occurs in the monsoon season (June-September), some rainfall also occurs during the pre-monsoon (March-May) and the post-monsoon (October-November) seasons, and a few showers may occur during the winter (December-February).

Drainage

The Terai is drained by numerous rivers and streams. The largest rivers are the Koshi in the east, the Gandaki in the centre, and the Karnali and the Mahakali in the west, all originating from the Himalayas or beyond. As the rivers cross the hills and the Churia Region, they start depositing huge sediments along their banks in the Terai Region. The deposition process creates multiple channels for the rivers. Most rivers are swollen up during monsoon season, causing flash floods in the Terai Region due to their shallow beds. One of the biggest concerns is the tendency of minor and major rivers to change their courses due to flooding events (Carson *et al.,* 1986).

1.3. Forest Resource Assessment (2010-2014)

The Terai forests were assessed first in the 1960s as part of Nepal's first national-level forest inventory that sequentially followed the second and third in 1980s and 1990s, each of those assessments differed in terms of purpose, scale, scope, design and technology. The recent and most comprehensive nationwide forest resource assessment (FRA) was implemented between 2010 and 2014 under the

[2]Based on data from 22 meteorological stations in the Terai (Department of Hydrology and Meteorology, 1979–2009).

FRA Nepal Project with technical and financial assistance from the Government of Finland. Four physiographic strata, i.e. the Terai, Churia, Middle Mountains, High Mountains and High Himal, were considered for the assessment. The assessment in the Terai physiographic region was carried out between 2010 and 2012. It revealed that the 'forest' and 'other wooded land (OWL)' covered 20.41% (411,580 ha) and 0.47% (9,502 ha), respectively, of the total area of the Terai physiographic region (DFRS, 2014).

CHAPTER 2: METHODOLOGY

2.1 Introduction

The forest resource assessment in the Terai included remeasurement of existing permanent sample plots (PSPs) as well as establishment and measurement of additional PSPs. The measurement of PSPs followed the standard field measurement protocols used in FRA-Nepal Project (DFRS, 2014). National scale remote sensing based forest cover mapping was also implemented.

2.2 Forest Inventory

2.2.1 Sample plot selection

The forest inventory involved remeasurement of the PSPs established by the FRA Nepal Project (2010-2014) and an additional number of plots established using the same methodology. The inventory design adopted was based largely on methods developed by Kleinn (1994) and finalised by the DFRS (Figure 2).

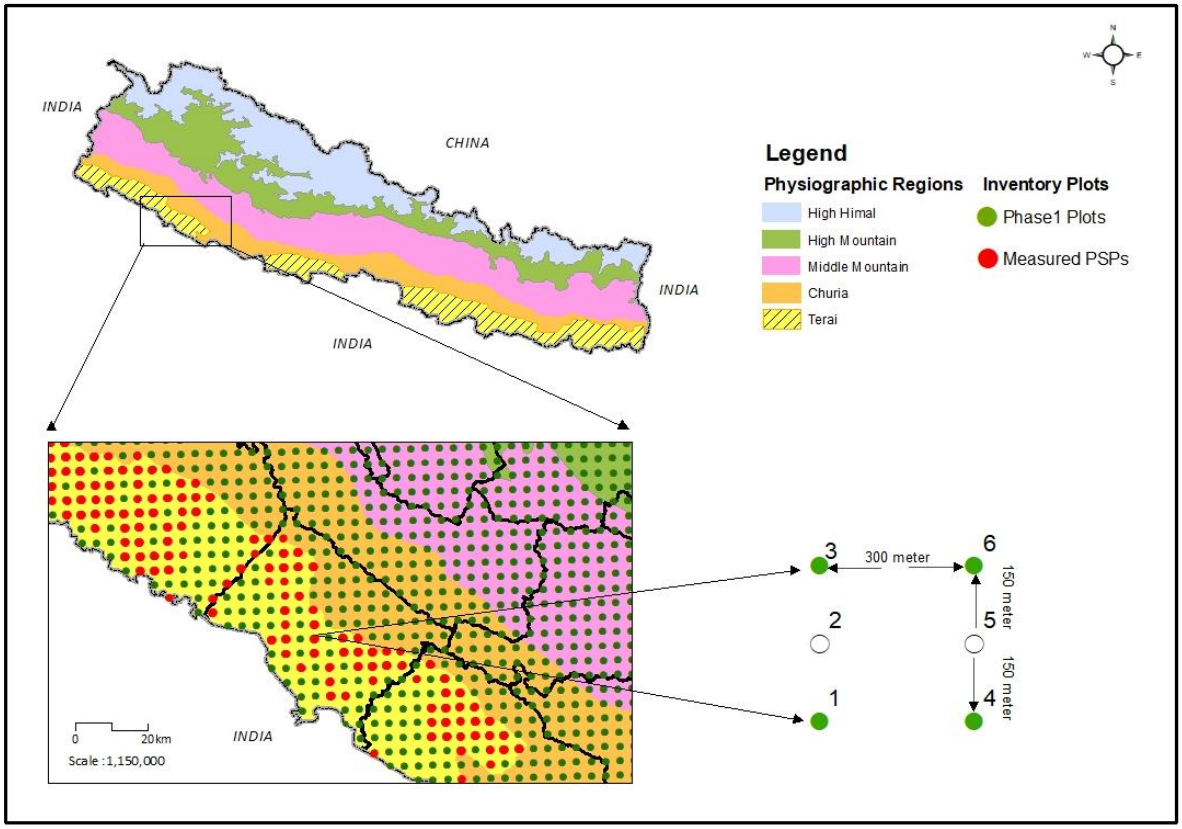

Figure 2: Layout of the clusters and plot within each cluster[3].

The detailed methodology adopted for sample selection is presented in DFRS, 2014. Altogether 367 plots (171 PSPs plus 196 additional PSPs from 55 clusters each) were selected for this assessment (Figure 3).

[3] In Terai, each cluster consists of four plots.

2.2.2 Sample plot design

The concentric circular sample plot (CCSP) design was adopted as used by the FRA Nepal Project (2010-2014). Each sample plot had four concentric circles of different radii (Figure 3), which were used to measure trees with different DBH as follows:

- trees having 30 cm DBH or more enumerated within a 20 m radius plot (area: 1256.6 m^2)
- trees having 20-29.9 cm DBH enumerated within a 15 m radius plot (area:706.9 m^2)
- trees having 10-19.9 cm DBH enumerated within an 8 m radius plot (area:201.0 m^2)
- trees having 5-9.9 cm DBH enumerated within a 4 m radius plot (area: 50.3 m^2)

Other subplots were established to assess forest attributes other than trees, such as seedlings, saplings, shrubs, and herbs. Seedlings, saplings, and shrubs were measured in four circular subplots of 2 m radius, located at 10 m from the plot centre in each cardinal direction. Species-wise, stem counting and mean height estimation was done for tree and shrub species with DBHs less than 5 cm. Besides, diameter of shrub was measured near the root collar. Information on non-woody vascular plants was collected from four 1 m^2 square plots, each located 5 m away from the plot centre in the four cardinal directions. Dead and decaying wood was assessed in a circular plot with a radius of 10 m from the plot centre. Based on field observations, 15 categories of natural and anthropogenic forest disturbances were assessed in terms of their occurrence and intensity (high, medium, low) on the sub-plot with a 20 m radius.

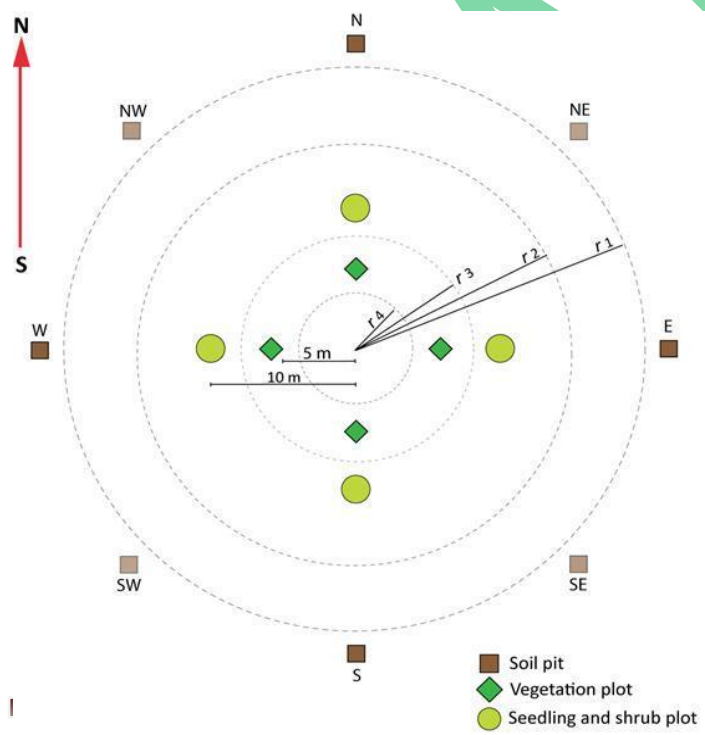

Figure 3: Layout of the concentric circular plot with other sub-plots

2.2.3 Quality assurance of forest inventory data

Use of periodically revised field manual, training to field crews and regular monitoring and feedback were some of the measures applied to maintain the quality of the inventory results. For the statistical analysis to check for the quality of the results, over 10% of the total PSPs measured were systematically selected (with a random start) and re-measured.

2.2.4 Tree height modelling

The total height of trees is an important predictor of volume and biomass. Still, its measurement for all trees under forest conditions can be time-consuming and impractical. On the other hand, diameter at breast height (DBH) is a frequently used tree characteristic in forest inventories as it is an easily measurable variable (Gering, 1995). The FRA field manual thus suggests to measure tree heights only for the sample trees. Furthermore, for top broken, dead trees and stumps, tree heights are measured at the existing tip. Hence, tree diameter height modelling is required to impute the heights for all those trees for which field measurements were not taken. The missing tree heights were imputed using the Naslund function (Equation 1) implemented in the R package *Lmfor* (Mehtatalo, 2012).

Equation 1: Naslund function for height imputation:

$$h(d) = bh + d^2/(a + b\,d)^2$$

where,

d	A vector of tree diameters, usually in cm
h	A vector of tree heights, usually in m.
a, b	Parameters a, b of the applied function.
bh	The applied height for measuring tree diameter (breast height), in m.

The details of the model parameters are listed in Annex 1.

2.2.5 Volume and biomass estimation

Tree volume estimation:

Equation 1, developed by Sharma and Pukkala (1990), was used to estimate tree volume over bark.

Equation 2: Tree volume

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

where,

ln = Natural logarithm to the base 2.71828.
V = Volume (dm^3) = exp [a + b×ln(DBH) + c×ln(h)]
d = DBH in cm
h = Total tree height in m
a, b and c are coefficients depending on species
Values were divided by 1000 to convert them into cubic meters.

The regression parameters for Equation 2 are presented in Table 1.

Table 1: Species-specific coefficients used for calculating volumes of individual trees

SN	Species	Local name	a	b	c	S_f
1	*Acacia catechu*	Khair	-2.3256	1.6476	1.0552	0.12
2	*Adina cordifolia*	Haldu	-2.5626	1.8598	0.8783	0.14
3	*Anogeissus latifolius*	Banjhi	-2.272	1.7499	0.9174	0.11
4	*Dalbergia sissoo*	Sissoo	-2.1959	1.6567	0.9899	0.12
5	*Syzygium cumini*	Jamun	-2.5693	1.8816	0.8498	0.12
6	*Hymanodictyon excelsum*	Bhurkul	-2.585	1.9437	0.7902	0.11
7	*Lagerstroemia parviflora*	Botdhainro	-2.3411	1.7246	0.9702	0.14

8	*Michelia champaca*	Champ	-2.0152	1.8555	0.763	0.14
9	*Shorea robusta*	Sal	-2.4554	1.9026	0.8352	0.13
10	*Terminalia alata*	Asna	-2.4616	1.8497	0.88	0.12
11	*Trewia nudiflora*	Gutel	-2.4585	1.8043	0.922	0.12
12	Miscellaneous in the Terai	-	-2.3993	1.7836	0.9546	0.16

Source: Sharma and Pukkala (1990)

The total volumes of broken trees were estimated using a taper curve equation developed by Heinonen *et al.* (1996), mentioned in Annex 2.

Tree stem biomass estimation:

The tree-stem biomass was calculated using Equation 3 (MFSC, 1988) and the species-specific wood-density values (Sharma and Pukkala, 1990) (Table 2). The air-dried biomass values obtained using these equations were converted into oven-dried biomass values by applying a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012) and a carbon-ratio factor of 0.47 (IPCC, 2006).

Equation 3: Tree stem biomass

$$\text{Stem biomass} = \text{Vol} \times \text{density}$$

where,

Vol = Stem volume in cubic meters
Density = Air-dried wood density (kg/m^3)

Table 2: Stem wood-density of Terai trees

SN	Species	Local name	Air-dried density (kg/m^3)
1	*Acacia catechu*	Khair	960
2	*Adina cordifolia*	Haldu/Karma	670
3	*Albizzia* spp.	Siris	673
4	*Anogeissus latifolius*	Banjhi	900
5	*Bombax ceiba*	Simal	368
6	*Dalbergia sissoo*	Sissoo	780
7	*Syzygium cumini*	Jamun	770
8	*Lagerstroemia parviflora*	Botdhainro	850
9	*Litsea monopetala*	Kutmiro	610
10	*Michelia champaca*	Champ	497
11	*Shorea robusta*	Sal	880
12	*Terminalia alata*	Asna/Saj	950
13	*Trewia nudiflora*	Gutel	452
14	Miscellaneous	-	674

Source: Sharma and Pukkala (1990)

Tree branch and foliage biomass estimation:

Separate branch-to-stem and foliage-to-stem biomass ratios for *Dalbergia sissoo, Shorea robusta* and the other TMH species mentioned in the MFSC (1988) for small (DBH < 28 cm), medium (DBH 28 – 53

cm) and large (DBH > 53 cm) trees were used to estimate branch and foliage biomass from stem biomass (Table 3).

Table 3: Branch-to-stem and foliage-to-stem biomass ratios of trees

SN	Species	Local name	Branch-to-stem			Foliage-to-stem		
			Small	Medium	Large	Small	Medium	Large
1	*Dalbergia sissoo*	Sissoo	0.684	0.684	0.684	0.01	0.01	0.01
2	*Shorea robusta*	Sal	0.055	0.341	0.357	0.062	0.067	0.067
3	Other TMH species	-	0.4	0.4	0.4	0.07	0.05	0.04

Source: MFSC (1988)

The total biomass of individual trees was estimated using Equation 4.

Equation 4: Total biomass of an individual tree

$$\text{Total biomass} = \text{Stem biomass} + \text{branch biomass} + \text{foliage biomass}$$

Tree stump and coarse root biomass estimation:

It was calculated using Equation 5 (Altrell *et al.,* n.d.).

Equation 5: Stump volume estimation

$$Vol_{stump} = (D_{sh}^2)/4 \times H_{stump} \times \pi \times F_{stump}$$

where,
D_{sh} = Stump diameter
H_{stump} = Stump height
F_{stump} = Stump form factor 1.5 (stump form-factors range from 1.3 to 2.0)

2.2.6 Reliability of estimates

The stem volume per hectare was considered as the main variable for assessing the reliability of results. The reliability was estimated in terms of standard error of the mean stem volume. The desired accuracy was 10 % at 95% confidence level. The variance of mean volume estimate in forest was estimated by using the variance estimator of a ratio estimator (Equation 6) proposed by Cochran (1977).

Equation 6: Variance of mean volume estimate

$$v(\bar{x}_p^{(F)}) = \frac{1}{(\sum^{n_p} m_i)^2} \frac{n_p}{n_p - 1} \sum^{n_p} \left(x_i - \bar{x}_p^{(F)} \cdot m_{p,i}\right)^2$$

Where,

n_p =number of clusters with at least one forest plot

$m_{p,i}$ = number of forest plots in cluster i

x_i = sum of plot level volumes in cluster i, m^3 /ha

$\bar{x}_n^{(F)}$ = mean volume in forest

p refers to physiographic region.

2.3 Forest Cover Mapping

Forest-cover maps for Terai were derived as a subset of the national land cover maps prepared by the National Land Cover Monitoring System (NLCMS) of Nepal (FRTC, 2022). In brief, the mapping method included collecting training samples for different land cover, preparation of annual Landsat composites, image indices and other covariates, predicting land cover maps using decision trees, and finally, validation and accuracy assessment (Figure 4).

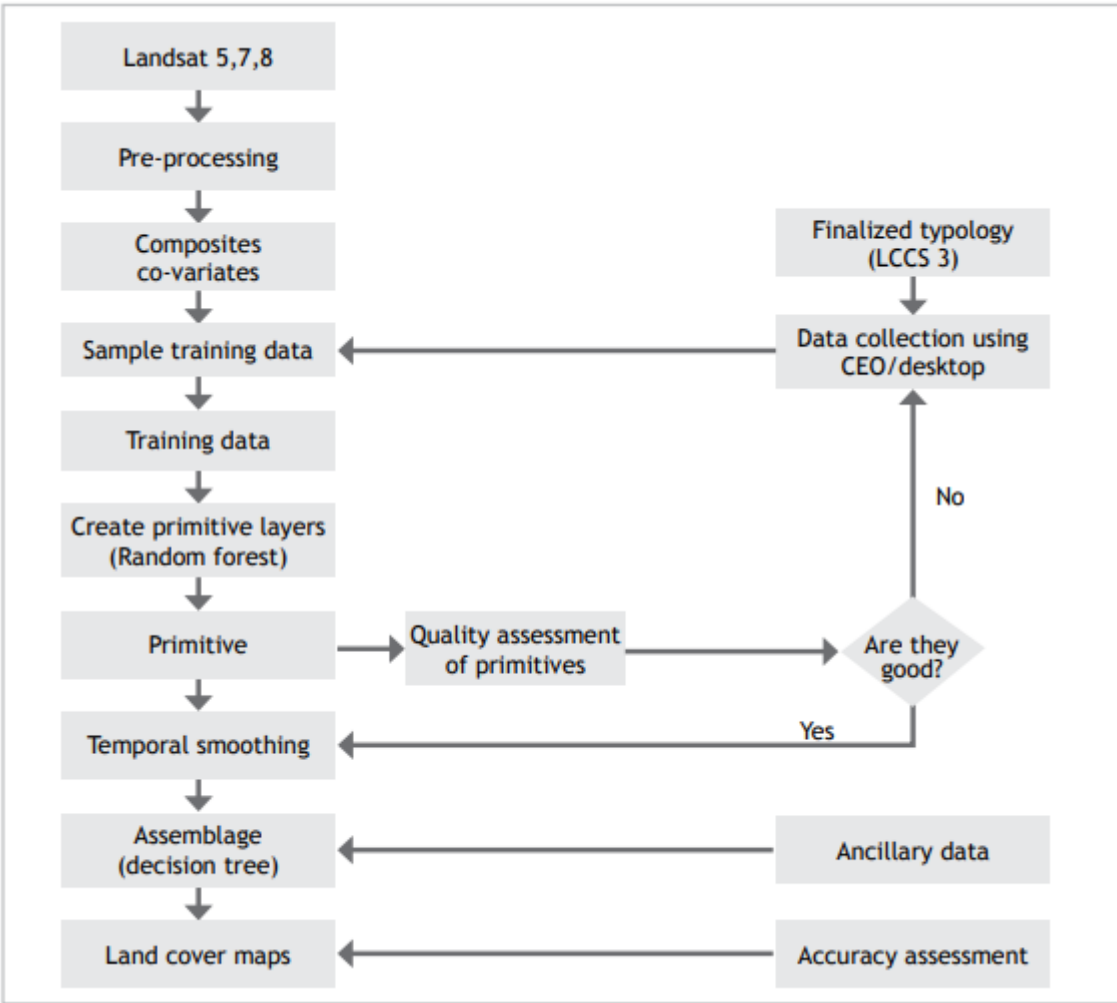

Figure 4: A flowchart showing the overall method of the NLCMS

2.4 Forest Soil Assessment

Soil samples were collected from the top 30cm soil layer in each plot and analysed in the accredited soil laboratory at the FRTC to estimate soil organic carbon (SOC) stock in the forests.

2.4.1 Collection of samples of litter, woody debris and soil from the field

Soil Sampling Locations

Soil sampling was conducted along the periphery of the CCSP established for forest inventory. The soil pits were dug 21 metres away from the CCSP-centre towards the four sub-cardinal directions, i.e. alternative soil pits, as shown in Figure 5. A composite sample of litter, woody debris, and soil was collected separately from each CCSP, except for the plots in the croplands, steep slopes (>100%), rocky areas, riverbanks, roads and water bodies. In the case of the CCSPs falling under two or more forest stands, the litter, debris, and soil samples were collected, establishing at least one soil pit within each stand.

Litter and Woody Debris Sampling

After locating the soil pits on the ground, litter and debris fractions were collected from 1 m^2 circular plots on the surface of each soil pit before taking soil samples. Litter and woody debris from all the four sub-plots were collected separately to make their composite samples. In the case of the pits without any litter or woody debris, the '0' value was recorded for the pit to estimate a correct average litter and debris mass per unit area.

The total composite fresh mass of both the litter and debris were weighed in the field to an accuracy of 1.0 g. If the total volumes of litter and debris collected from the 4-m^2 area, (four 1m^2 plots) were very large, one-quarter or one-half of the total samples were taken to determine their dry mass in the laboratory.

Soil Sampling

To collect undisturbed soil samples, soil pits of appropriate size were dug within a 2 m × 2 m area. The undisturbed soil samples were collected using a Cylindrical Corer having 40 mm diameter (37 mm diameter at its cutting-edge) and 100 mm length; the volume of each soil sub-sample being 107.5 cm^3.

The FRA field manual specified collecting the composite soil samples from three layers: 0-10 cm, 10-20 cm, and 20-30 cm depths from each cardinal direction (Figure 5). However, to avoid the disturbed soil during the FRA 2010-2014, soil samples were collected from the four sub-cardinal directions in second measurement. The fresh mass of the composite sample was determined with the accuracy of 1 gram. The soil samples from three layers were collected separately in the polythene bags from the field and brought to the laboratory; the samples were kept separately to assess the within-site variability of SOC.

The relative volume of stones in the soil was estimated by observing the soil pit walls and using the FAO Guidelines (2006).

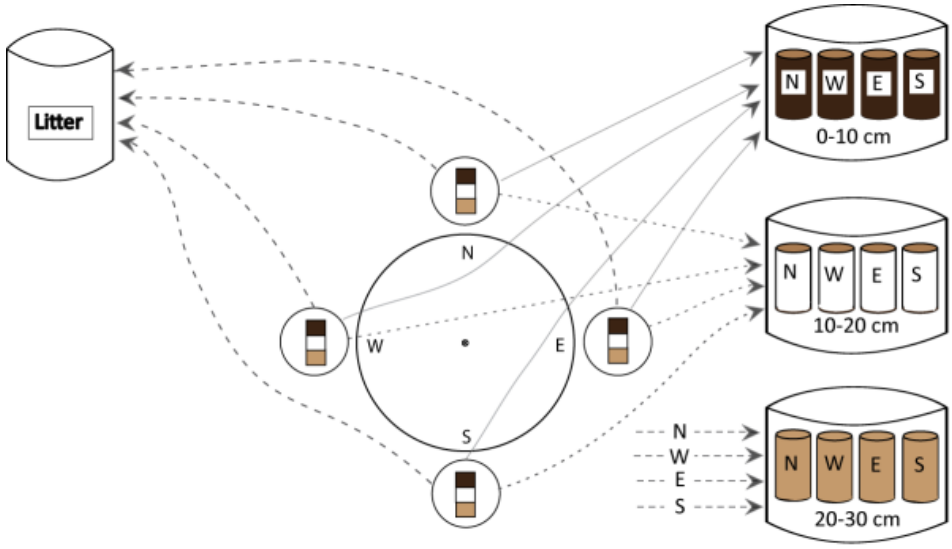

Figure 5: Collection of composite samples of litter, debris and soil from a plot

2.4.2 Analyses of samples in the laboratory

Determination of Physical Parameters

The composite samples of soil, litter and woody debris were analysed in the soil laboratory. SOC was calculated from dry soil bulk density (g/cm^3) and the proportion of soil organic carbon. Dry bulk density of the fine soil fraction (< 2mm) was determined from the volumetric composite samples to calculate the soil organic carbon stock in each 10 cm deep layer down to 30 cm below the soil surface. Before analysis, pebbles, gravels, and stones >2 mm were removed from the soil samples. All the particles less than 20 mm in diameter found in the volumetrically cored samples were eliminated to calculate the bulk density of the fine fraction.

The coarse fraction was separated using a 2 mm sieve, and its volume was measured using the water displacement method to calculate the bulk density of the fine fraction. The fine fraction that passed through the sieve was homogenised and analysed for OC%. The overall 0-30 cm soil layer SOC stock (t/ha) was derived by multiplying the OC% with the fine fraction bulk density of the respective sample, and it was further corrected with the proportion of large stones estimated for the 30 cm deep soil layer. The correction was applied using average values of SOC (t/ha) and the average stone volume of the strata reported in the results. Results of each 10 cm layer kept separate in analyses were summed to obtain SOC stored in the fine fraction of 0-30 cm soil layer.

Litter, Woody Debris, and Soil Carbon Analysis

The preparation of the samples and the SOC analysis followed the procedures detailed in the Laboratory SOP (FRA Nepal, 2011), as summarised below. Litter and woody debris were not analysed for OC%, but a constant carbon content of 50% (Pribyl, 2010) was applied with an estimate of dry mass/m^2. The oven-dry weight of the litter and woody debris was estimated by multiplying the ratio of oven-dry weight to the fresh weight of the litter and woody debris subsamples.

Before oven drying to achieve a constant weight and moisture content, the soil samples brought from the field to the FRTC laboratory were first air-dried until they were fully stabilised. Walkley-Black Wet Combustion Method (Walkley and Black, 1934), together with titration, was applied to analyse the proportion of OC% in the soil. As this method can recover only about 77 % of SOC, a correction factor of

1.33 was applied to determine the actual amount of SOC. An excel application was produced to collect all laboratory calculations and help organise and speed up the laboratory calculations. The application also calculated the carbon stocks of litter, woody debris, and soil fine fraction.

2.5. Limitations of the results

2.5.1 Forest inventory

The methodology was designed to collect data on tree volume and biomass in the entire Terai region with 95% confidence of being within plus or minus 10% of the actual value. The application of results for any sub-populations, such as a district or province, would be limited. Similarly, the confidence level of results for parameters other than tree volume and biomass could be lower.

Sampling errors can only be assessed if estimated values are distributed normally and there is no bias. Besides, other potential sources of inaccuracy include errors in identifying species, taking field measurements, entering field results in the database, and deriving and calculating mathematical formulae. Errors in area estimation influence the total values of growing stock, biomass and carbon while converting from average values.

The inventory data analysis relied on the biomass equations developed by Sharma and Pukkala (1990) developed using the data measured in the 1960s. In addition, there were insufficient species-specific wood densities available for the tree species. Stem to branch and foliage biomass ratios were available only for a few species (Table 3). The biomass values obtained from the biomass tables provide only air-dry biomass values. These limitations might influence the precision of estimating above and belowground wood biomass and carbon content in the Terai Forests.

Result of biodiversity analysis provides indicative figures of abundance of species in sample plots level. Number of family genera and species for shrubs and NTFPs is taken from sample plots only, unlike FRA 2010-2014 where those were considered from social survey as well.

2.5.2 Forest cover mapping

Potential sources of uncertainty in forest cover maps could be introduced due to limited coverage of high-resolution satellite images for earlier years in contrast to more frequent and quality reference images available for recent years. As the Landsat allows coarser scale mapping (e.g. 30 m spatial resolution equivalent to 0.09 ha), many small scale land cover and changes are not represented in the maps. Therefore, the area estimates are expected to vary with the previous estimates derived in FRA 2010-2014. Due to the spatial heterogeneity of the forest stands and the fuzziness of their boundary limits, errors might have been introduced in the classification and delineation of such forest stands.

2.5.3 Soil analysis

Soil sampling was done only in the sample plots designed for the forest inventory, specifically the tree volume and biomass estimation. Therefore, it might not have represented all the micro-site variabilities within the Terai Region. As a result, the confidence intervals of the estimates were appeared to be wide. Bringing samples from field to FRTC soil laboratory can often take long duration, which may lower the quality of sample and may affect the results.

CHAPTER 3: RESULTS

3.1. Area Statistics of the Terai Forest

Forest and Other Wooded Land (OWL) occupy 19.43 % (392,240 ha) and 0.86 % (17,338 ha) of the total area of the Terai region, respectively. Thus, Forest and OWL together cover 20.29 % of the total land cover in the Terai (Table 4).

Table 4: Land cover in the Terai, 2019

Land cover class	Area	
	Ha	%
Forest	392,240	19.43
Other Wooded Land (OWL)	17,338	0.86
Other land	1,609,372	79.71
Total	**2,018,950**	

The land cover map of the Terai physiographic region is presented in Figure 6.

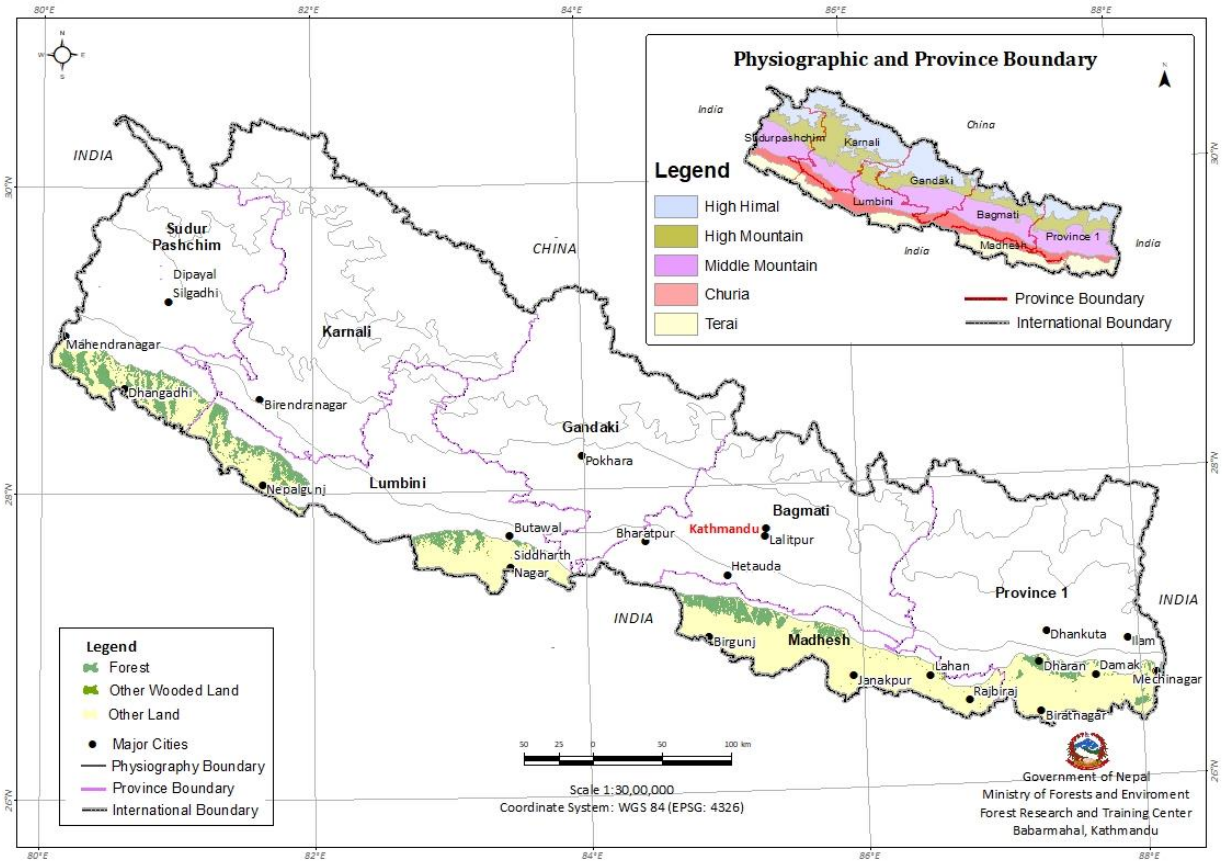

Figure 6: Land cover map of the Terai region, 2019

3.2. Terai Forest Inventory Results

The main results presented here include the number of stems, basal area, volume, biomass, and carbon stock. Furthermore, results on forest disturbances, shrubs and small trees (seedling/sapling), biodiversity, and NTFPs are also included. The species that contribute one percent or above to the total growing stock of the Terai forests are included in the result tables and graphs.

3.2.1 Number of stems (DBH>=5 cm)

The Terai forests of Nepal contain a total of 241.57 million live stems with DBH>=5cm, the average being 615.87 per hectare. There are 3.81 million standing dead stems (9.72 per hectare), of which more than 80 percent are usable. Co-dominant stems constitute the highest proportion of stems in the Terai forests, followed by dominant ones. About 8.5 stems per hectare were removed annually in the last five years by different natural and anthropogenic causes (Table 5).

Table 5: Number of stems per ha by crown class

Status of stem	Crown class	No. of stems/ha
Live stems	Dominant	173.30
	Co-dominant	195.69
	Intermediate	172.02
	Suppressed	29.35
	Understory	4.94
	Top-broken	40.56
Sub-total **(live stems)**		**615.87**
Standing dead stems	Dead usable	7.83
	Dead unusable	1.88
Sub-total **(standing dead stems)**		**9.72**
Stem removal (last five years)		**42.43**

Shorea robusta is the most abundant species in the Terai forests (155.7/ha), followed by *Mallotus philippensis* (79.4/ha). The numbers of saplings (5-10 cm), poles (10-20 cm), small saw-timber (20-50 cm) and large saw-timber (50 cm or above) are 314.7, 177.9, 98.4 and 24.9, respectively. The average weighted DBH and height of stems are 48.1 cm and 22.6 m, respectively, with *Adina cordifolia* having the largest ones (Average weighted DBH=88.7 cm and Average weighted height=29.2 m) (Table 6).

Table 6: Number of stems per ha by species and DBH class

SN	Species	Number of stems/ha in DBH classes (cm)						Average weighted DBH (cm)	Average Weighted height (m)
		5-10	10-20	20-30	30-50	>50	Total		
1	*Acacia catechu*	7.2	6.2	2.5	0.6	0.1	16.5	25.3	13.9
2	*Adina cordifolia*	1.6	1.1	0.6	0.6	1.2	5.1	88.7	29.2
3	*Anogeissus latifolia*	14.1	9.4	2.1	1.7	0.5	27.8	35.6	21.3
4	*Buchanania latifolia*	11.4	8.5	2.9	0.9	0.0	23.8	22.1	13.4
5	*Dillenia pentagyna*	8.7	2.4	1.2	0.8	0.3	13.4	37.6	17.2
6	*Eugenia jambolana*	9.8	2.5	1.5	0.9	0.7	15.4	48.9	19.4
7	*Lagerstroemia parviflora*	12.5	10.8	4.3	2.1	0.4	30.0	31.0	19.0
8	*Lannea coromandelica*	2.2	2.2	1.3	1.2	0.5	7.4	44.0	19.8

9	*Mallotus philippensis*	45.0	25.6	6.9	1.7	0.1	79.4	21.0	12.0
10	*Shorea robusta*	73.2	39.0	13.1	16.0	14.4	155.7	56.4	26.5
11	*Terminalia alata*	23.3	14.5	4.0	4.2	3.7	49.7	56.2	27.5
12	*Terminalia bellirica*	4.3	1.8	1.4	1.2	0.6	9.4	51.7	24.7
13	Others	101.5	53.9	16.2	8.2	2.4	182.2	34.9	16.0
	Total	**314.7**	**177.9**	**58.2**	**40.2**	**24.9**	**615.9**	**48.1**	**22.6**

The majority of stems (62%) in the Terai forests is in the quality class III, termed here as cull trees, and followed by sound trees (quality-II) with 21%. Only 17% of stems are classified as high-quality sound trees i.e. quality-I (Figure 7).

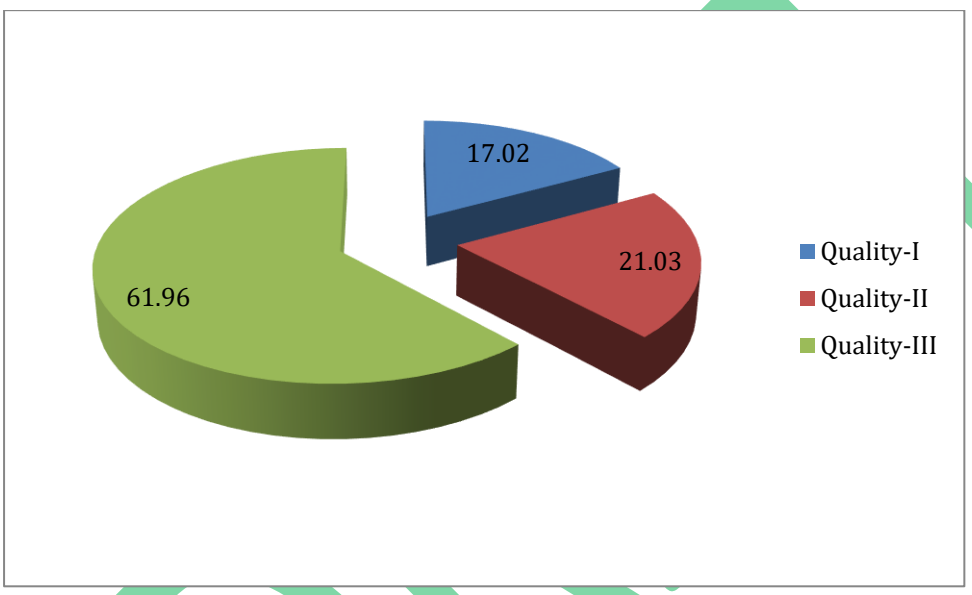

Figure 7: Number of stems by quality classes expressed as percentage

Shorea robusta, the most abundant and one of the most valuable timber-yielding species in the Terai, has the largest number of high-quality stems, with about 39% and 32% of its stems in quality-I and quality-II, respectively. However, more than 92% of stems of *Mallotus philippensis*, the second most abundant species in the Terai forests, are in quality-III (Table 7).

Table 7: Number of stems per ha by species and quality class

S.N.	Species	Number of stems/ha in quality class			Total
		Quality-I	Quality-II	Quality-III	
1	*Acacia catechu*	0.7	2.3	13.5	16.5
2	*Adina cordifolia*	1.1	1.2	2.8	5.1
3	*Anogeissus latifolia*	5.2	7.7	14.9	27.8
4	*Buchanania latifolia*	1.9	5.8	16.1	23.8
5	*Dillenia pentagyna*	0.8	0.6	12.1	13.4
6	*Eugenia jambolana*	1.1		11.9	15.4

			2.4		
7	*Lagerstroemia parviflora*	3.8	6.3	20.0	30.0
8	*Lannea coromandelica*	1.0	2.3	4.2	7.4
9	*Mallotus philippensis*	0.2	6.0	73.2	79.4
10	*Shorea robusta*	60.2	50.1	45.4	155.7
11	*Terminalia alata*	17.3	12.8	19.6	49.7
12	*Terminalia bellirica*	2.7	2.7	4.0	9.4
13	Others	9.0	29.3	144.0	182.2
	Total	**104.8**	**129.5**	**381.6**	**615.9**

3.2.2 Number of seedlings and saplings

The number of seedlings (DBH < 5 cm, height < 1.3 m) and saplings (DBH < 5 cm, height > 1.3 m) in the Terai forests are 12,777 and 2,370 per hectare, respectively. Like the larger stems, *Shorea robusta* has the largest number of seedlings and saplings, followed by *Mallotus philippensis* (Table 7).

Table 7: Number of seedlings and saplings per ha by species

SN	Species	Seedling	Sapling	Total
1	*Acacia catechu*	24	15	39
2	*Adina cordifolia*	14	12	26
3	*Anogeissus latifolia*	23	40	63
4	*Buchanania latifolia*	229	28	257
5	*Dillenia pentagyna*	67	31	98
6	*Eugenia jambolana*	571	100	671
7	*Lagerstroemia parviflora*	46	34	80
8	*Lannea coromandelica*	16	5	21
9	*Mallotus philippensis*	1121	499	1619
10	*Shorea robusta*	7707	970	8677
11	*Terminalia alata*	422	82	505
12	*Terminalia bellirica*	54	21	75
13	Others	2483	534	3017
	Total	**12777**	**2370**	**15147**

Regenerations of *Shorea robusta* are dominant in all forest types except Khair/Sissoo forest, out of which the highest number of its regenerations is in Sal forests (14,973 seedlings and 2,791 saplings/ha), followed by Terai Mix Hardwood (TMH) forests (12,224 seedlings and 2,297 saplings/ha). Regenerations

of all the 12 species that contribute at least one percent to the total stem volume of the Terai forests are presented in Table 8.

Table 8: Number of seedlings and saplings per ha by species and forest types

SN	Species	Forest type							
		KS/SK (7 plots)		Sal (107 plots)		STMH (7 plots)		TMH (246 plots)	
		Seedling	Sapling	Seedling	Sapling	Seedling	Sapling	Seedling	Sapling
1	*Acacia catechu*	199	199	9	4	0	0	27	15
2	*Adina cordifolia*	0	0	9	2	0	0	17	17
3	*Anogeissus latifolia*	0	0	2	7	0	0	33	57
4	*Buchanania latifolia*	0	0	162	37	171	0	267	25
5	*Dillenia pentagyna*	0	0	99	15	142	114	53	36
6	*Eugenia jambolana*	0	0	496	87	0	0	636	112
7	*Lagerstroemia parviflora*	0	0	52	26	0	0	46	39
8	*Lannea coromandelica*	0	0	30	17	0	0	11	0
9	*Mallotus philippensis*	0	0	766	444	540	0	1324	550
10	*Shorea robusta*	0	0	10923	1712	5826	57	6581	700
11	*Terminalia alata*	0	0	366	78	227	0	464	89
12	*Terminalia bellirica*	0	0	52	2	0	0	57	31
13	Others	1194	199	2006	359	3155	284	2707	627
	Total	**1393**	**398**	**14973**	**2791**	**10061**	**455**	**12224**	**2297**

KS/SK = Khair-Sissoo/Sissoo-Khair, STMH = Sal Terai Mixed Hardwood, TMH = Terai Mixed Hardwood

The total number of seedlings and saplings has increased with an increase in canopy cover class. Similarly, the number of seedlings and saplings has increased with an increase in the development stage of a forest. In terms of forest management regimes, protected forests have the highest number of regeneration (17,382/ha), followed by collaborative forests (16,205/ha) (Table 9).

Table 9: Number of seedlings and saplings by different forest attributes

SN	Forest attributes	No. of plots	Seedling	Sapling	Total
	Canopy cover				
1	< 40 %	51	6846	1347	8193
2	40-70 %	217	13468	2288	15755
3	> 70 %	99	14320	3077	17397
	Average	**367**	**12777**	**2370**	**15147**
	Development stage				
1	Seedling and sapling stand (< 12.5 cm DBH)	8	4750	696	5446
2	Pole -timber stand (12.5 - 25.0 cm DBH)	80	8376	1759	10135

3	Small saw-timber stand (25.0 - 50.0 cm DBH)	121	14308	2172	16479
4	Large saw-timber stand (> 50.0 cm DBH)	158	14241	2915	17156
	Average	**367**	**12777**	**2370**	**15147**
	Management regime				
1	Government-managed forest	72	13846	1592	15437
2	Protected forest	73	15377	2005	17382
3	Buffer zone (community-managed)	27	8157	2815	10971
4	Community-managed forest	147	11672	2736	14409
5	Collaborative forest	46	13377	2828	16205
	Average	**365***	**12777**	**2370**	**15147**

* Two plots, each from Private Forest and Buffer Zone (government-managed), were excluded from the analysis.

3.2.3 Basal area

The basal area of live stems (DBH >= 5 cm) in the Terai forests is 20.88 m^2 per hectare. Dominant stems constitute the highest proportion of basal area 13.87 m^2 per hectare, followed by co-dominant ones 4.03 m^2 per hectare (Table 10).

Table 10: Basal area per ha by crown class

Status of stem	Crown class	Basal area m^2/ha	Percent
Live stems	Dominant	13.87	66.44
	Co-dominant	4.03	19.31
	Intermediate	1.72	8.25
	Suppressed	0.18	0.87
	Understory	0.03	0.15
	Top-broken	1.04	4.98
Sub-total **(live stems)**		**20.88**	
Standing dead stems	Dead usable	0.42	
	Dead unusable	0.03	
Sub-total **(standing dead stems)**		**0.45**	
Stem removal (last 5 years)		**0.45**	

Shorea robusta constitutes the largest proportion of basal area in the Terai forests (42.11%), followed by *Terminalia alata* (11.48%). In terms of stem size, the largest DBH class (>= 50 cm), which comprises the stems expected to produce large saw-timber, has the largest proportion (44%) of the total basal area (Table 11).

Table 11: Basal area per ha by species and DBH class

SN	Species	DBH (cm) class and basal area (m^2/ha)					Total	Percent
		5-10	10-20	20-30	30-50	>50		
1	*Acacia catechu*	0.0	0.1	0.1	0.1	0.0	0.3	1.44
2	*Adina cordifolia*	0.0	0.0	0.0	0.1	0.6	0.8	3.83
3	*Anogeissus latifolia*	0.1	0.1	0.1	0.2	0.2	0.7	3.35
4	*Buchanania latifolia*	0.0	0.1	0.1	0.1	0.0	0.4	1.91

5	*Dillenia pentagyna*	0.0	0.0	0.1	0.1	0.1	0.3	1.44
6	*Eugenia jambolana*	0.0	0.0	0.1	0.1	0.2	0.5	2.39
7	*Lagerstroemia parviflora*	0.1	0.2	0.2	0.2	0.1	0.8	3.83
8	*Lannea coromandelica*	0.0	0.0	0.1	0.1	0.2	0.4	1.91
9	*Mallotus philippensis*	0.2	0.4	0.3	0.2	0.0	1.1	5.26
10	*Shorea robusta*	0.3	0.6	0.6	2.0	5.3	8.8	42.11
11	*Terminalia alata*	0.1	0.2	0.2	0.5	1.4	2.4	11.48
12	*Terminalia bellirica*	0.0	0.0	0.1	0.2	0.2	0.5	2.39
13	Others	0.4	0.9	0.8	0.9	0.8	3.8	18.18
	Total	**1.3**	**2.9**	**2.7**	**4.7**	**9.2**	**20.9**	**100**

3.2.4 Stem volume

The total volume of live stems (DBH >= 5 cm) in the Terai forests is 78.78 million m^3 (200.86 m^3/ha). Dominant stems constitute the highest proportion of stem volume (74.24%), followed by co-dominant ones (16.12%). The total volume of standing dead stems is 1.44 million m^3 (3.68 m^3/ha), of which more than 95 percent is usable. A total of 1.44 million m^3 (3.66 m^3/ha) of stem volume is estimated to have been removed in the last five years (Table 12).

Table 12: Stem volume per ha by crown class

Status of stem	Crown class	Stem volume(m^3/ha)	Stem volume/ha (%)
Live stems	Dominant	149.12	74.24
	Co-dominant	32.39	16.12
	Intermediate	10.88	5.42
	Suppressed	0.97	0.49
	Understory	0.17	0.08
	Top-broken	7.33	3.65
Sub-total **(live stems)**		**200.86**	**100**
Standing dead stems	Dead usable	3.52	
	Dead unusable	0.16	
Sub-total **(standing dead stems)**		**3.68**	
Stem removal (last five years)		**3.66**	

Shorea robusta constitutes largest stem volume per ha (99.8 m^3/ha) in the Terai forests, followed by *Terminalia alata* (26.2 m^3/ha). In terms of stem size, the growing stock has increased with an increase in DBH class (Table 13).

Table 13: Stem volume per ha by species and DBH class

SN	Species	DBH (cm) class and stem volume (m^3/ha)					Total
		5-10	10-20	20-30	30-50	>50	

1	*Acacia catechu*	0.1	0.6	0.8	0.4	0.2	2.2
2	*Adina cordifolia*	0.0	0.1	0.3	0.5	6.8	7.7
3	*Anogeissus latifolia*	0.3	1.0	0.9	1.9	1.7	5.8
4	*Buchanania latifolia*	0.2	0.8	1.0	0.7	0.0	2.8
5	*Dillenia pentagyna*	0.1	0.2	0.4	0.8	0.9	2.4
6	*Eugenia jambolana*	0.1	0.2	0.5	0.7	2.1	3.6
7	*Lagerstroemia parviflora*	0.3	1.2	1.6	2.3	0.9	6.3
8	*Lannea coromandelica*	0.0	0.3	0.5	1.3	1.5	3.7
9	*Mallotus philippensis*	0.8	2.4	2.3	1.3	0.2	7.0
10	*Shorea robusta*	1.5	4.8	5.8	22.5	65.3	**99.8**
11	*Terminalia alata*	0.5	1.6	1.7	5.3	17.2	**26.2**
12	*Terminalia bellirica*	0.1	0.3	0.7	1.6	2.7	5.3
13	Others	1.8	5.1	5.7	7.5	7.8	27.9
	Total	**5.7**	**18.7**	**22.2**	**46.9**	**107.3**	**200.9**

High-quality sound trees (quality-I) have the largest contribution, 65 % of the total stem volume in the Terai forests, followed by sound trees (quality-II) and cull trees (quality-III), with 18.8% and 16.2%, respectively. Over 80% of the stem volume of *Shorea robusta* and *Terminalia alata*, the two most dominant species belong to quality-I stem (Table 14).

Table 14: Stem volume per ha by species and quality class

SN	Species	Stem volume (m3/ha) by stem quality			
		Quality-I	Quality-II	Quality-III	Total
1	*Acacia catechu*	0.4	0.5	1.3	2.2
2	*Adina cordifolia*	5.8	1.1	0.7	7.7
3	*Anogeissus latifolia*	3.2	1.6	1.0	5.8
4	*Buchanania latifolia*	0.5	1.2	1.0	2.8
5	*Dillenia pentagyna*	0.9	0.4	1.1	2.4
6	*Eugenia jambolana*	1.4	1.0	1.2	3.6
7	*Lagerstroemia parviflora*	2.5	1.8	2.0	6.3
8	*Lannea coromandelica*	1.5	1.5	0.7	3.7
9	*Mallotus philippensis*	0.1	0.8	6.1	7.0
10	*Shorea robusta*	80.9	15.0	3.9	99.8
11	*Terminalia alata*	21.6	3.0	1.5	26.2
12	*Terminalia bellirica*	3.7	1.4	0.2	5.3
13	Others	7.8	8.5	11.7	27.9
	Total	**130.5**	**37.9**	**32.5**	**200.9**

The total stem volume and volume of stems up to 10 cm top diameter and up to 20 cm top diameter without bark are 158.9, 148.4 and 125.9 cubic meters per hectare respectively (Table 15).

Table 15: Stem volume without bark per ha by species

SN	Species	Stem volume without bark (m^3/ha)		
		Total stem	Up to 10 cm top diameter	Up to 20 cm top diameter
1	*Acacia catechu*	1.7	1.4	0.7
2	*Adina cordifolia*	6.1	6.1	5.9
3	*Anogeissus latifolia*	5.2	4.5	3.3
4	*Buchanania latifolia*	2.2	1.8	0.9
5	*Dillenia pentagyna*	2.0	1.8	1.5
6	*Eugenia jambolana*	2.8	2.6	2.3
7	*Lagerstroemia parviflora*	4.9	4.4	2.8
8	*Lannea coromandelica*	3.2	3.0	2.5
9	*Mallotus philippensis*	5.4	4.1	1.9
10	*Shorea robusta*	77.5	74.9	68.4
11	*Terminalia alata*	20.6	19.7	17.7
12	*Terminalia bellirica*	4.6	4.4	3.8
13	Others	22.7	19.7	14.2
	Total	**158.9**	**148.4**	**125.9**

Stem volume without bark disaggregated by stem quality class and up to 10 and 20 cm top diameter is presented in Table 16.

Table 16: Stem volume without bark per ha by species and quality class

SN	Species	Stem quality class and volume without bark (m^3/ha)								
		Quality-I			Quality-II			Quality-III		
		Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.	Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.	Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.
1	*Acacia catechu*	0.3	0.3	0.2	0.4	0.4	0.2	0.9	0.7	0.3
2	*Adina cordifolia*	4.7	4.7	4.7	0.8	0.8	0.7	0.6	0.5	0.5
3	*Anogeissus latifolia*	2.9	2.8	2.3	1.4	1.2	0.8	0.9	0.6	0.3
4	*Buchanania latifolia*	0.4	0.4	0.3	1.0	0.9	0.5	0.8	0.5	0.1
5	*Dillenia pentagyna*	0.8	0.8	0.7	0.4	0.4	0.3	0.9	0.7	0.5
6	*Eugenia jambolana*	1.2	1.2	1.1	0.7	0.7	0.6	0.9	0.8	0.6
7	*Lagerstroemia parviflora*	2.1	2.0	1.6	1.4	1.3	0.8	1.4	1.1	0.4
8	*Lannea coromandelica*	1.3	1.3	1.2	1.3	1.2	1.0	0.6	0.5	0.3
9	*Mallotus philippensis*	0.1	0.1	0.1	0.6	0.5	0.2	4.7	3.5	1.6
10	*Shorea robusta*	63.6	62.4	57.8	11.3	10.4	9.0	2.7	2.2	1.6
11	*Terminalia alata*	17.3	16.9	15.7	2.2	1.9	1.4	1.1	0.8	0.6
12	*Terminalia bellirica*	3.3	3.2	3.0	1.1	1.1	0.8	0.2	0.1	0.1
13	Others	6.6	6.4	5.6	6.9	6.3	4.7	9.1	6.9	3.9
	Total	**104.5**	**102.3**	**94.2**	**29.7**	**27.1**	**20.9**	**24.7**	**19.0**	**10.7**

dia. = diameter

3.2.5 Biomass

The Terai forests contain a total of 118.97 million tons of air-dry biomass (303.32 t/ha), equivalent to 108.16 million tons of oven-dry biomass (275.72 t/ha). Almost 80 % of the total biomass is represented by the aboveground components, i.e. live stems (76.66%), dead stems (1.03%), and deadwood (2.31%). Among the three components of live trees, stem and branch share over 70 % and 25% of the total biomass respectively. Thus the total oven dry biomass in the Terai forest (including live stem, dead stems, dead woods, and below ground biomass) is 275.72 tons per hectare (Table 17).

Table 17: Biomass in the Terai forests (DBH>=5 cm)

Biomass components		Air-dry biomass (t/ha)
Aboveground	**Tree components**	
1. Live stems	Stem	163.94
	Branch	58.92
	Foliage	9.66
	Sub-total (a)	**232.53**
2. Dead stems	Stem	3.12
	Branch	0.00
	Foliage	0.00
	Sub-total (b)	**3.12**
3. Dead wood (c)		**7.01**
Total Aboveground biomass (AGB) (a+b+c)		**242.66**
Below ground biomass (BGB) (@ 25% of total AGB)		**60.66**
Total air-dry biomass (AGB + BGB)		**303.32**
Total oven-dry biomass (@ 90.90 % of the total air dry biomass)		**275.72 t/ha**

In terms of species, *Shorea robusta* contributes more than half of the total air-dry biomass of live trees, followed by *Terminalia alata* (Figure 8).

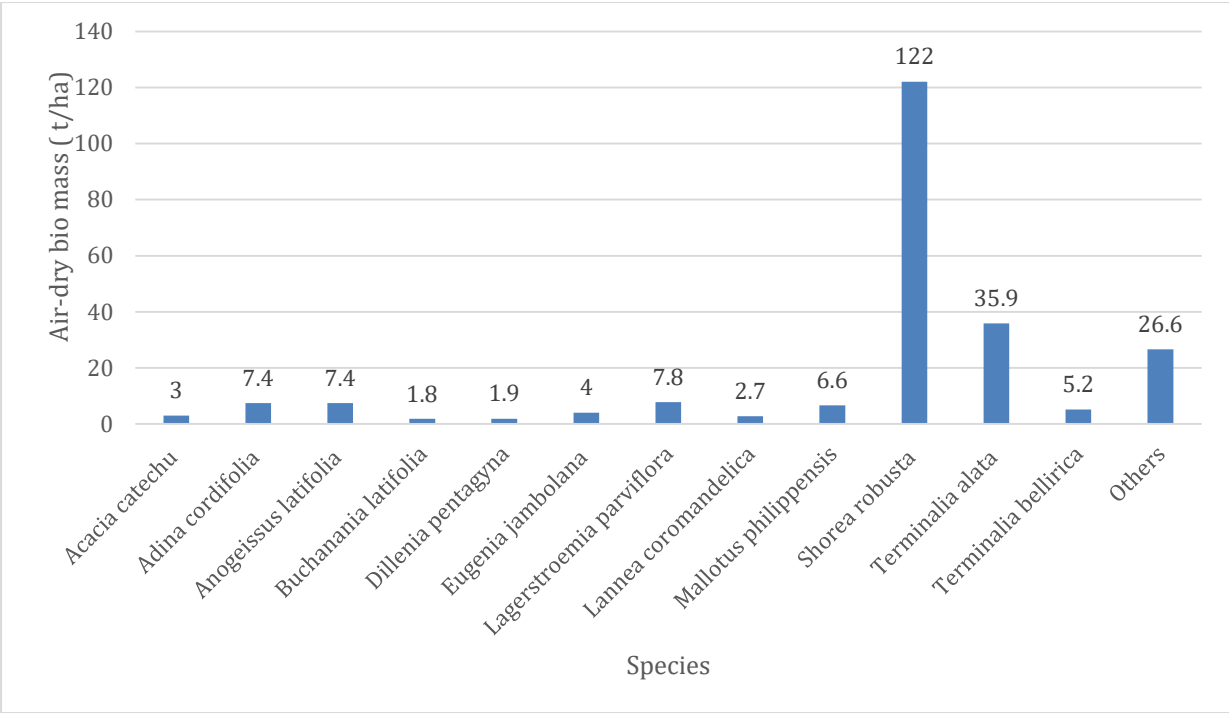

Figure 8: Aboveground biomass (air-dry) of live stems (DBH>=5cm) by species (t/ha)

3.2.6 Forest disturbances

A range of disturbances occurs in the Terai forests. Livestock grazing, tree cutting, forest fire, and sapling/pole cutting are the most prevalent disturbances occurring (Figure 9).

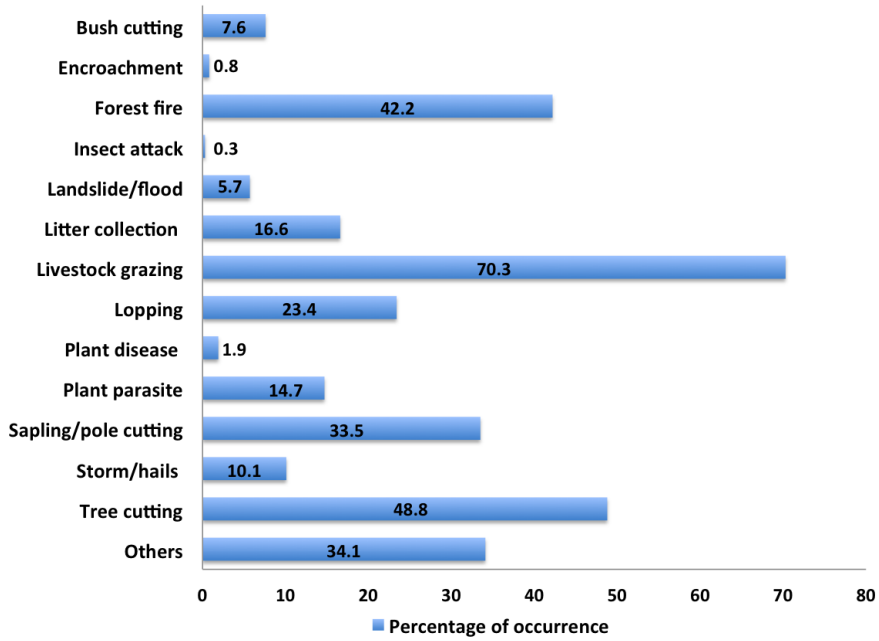

Figure 9: Occurrence of forest disturbances

Analysis of observation in PSPs showed that the frequency of different types of disturbances varies in different forest management regimes. Despite the differences in frequencies, all forest management regimes experienced some sort of disturbances (Figure 10).

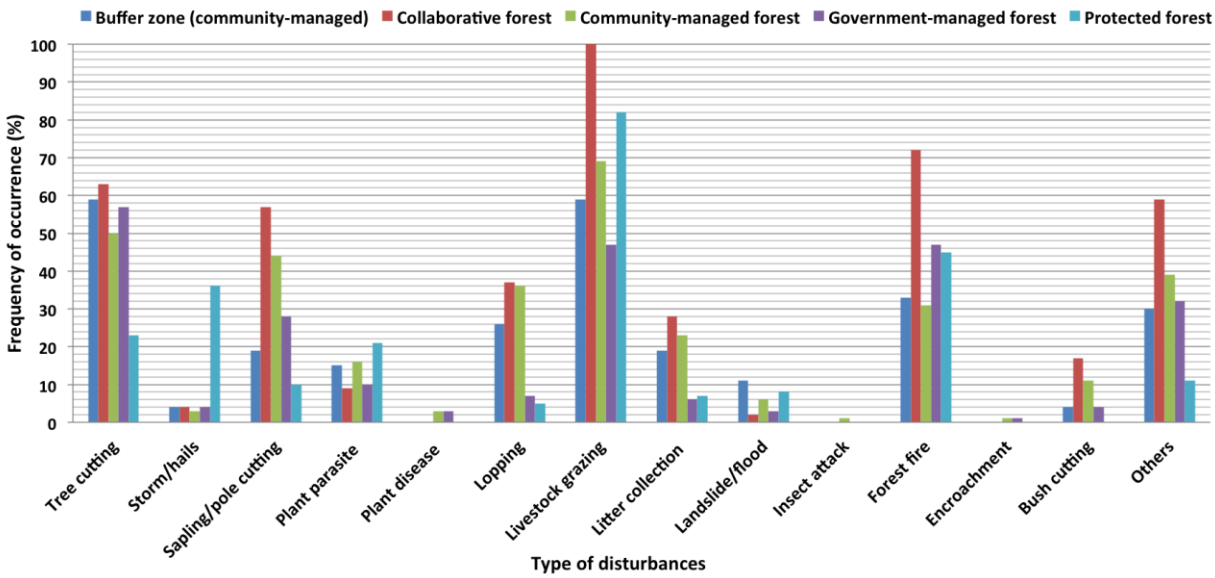

Figure 10: Occurrence of forest disturbances by forest management regimes

3.2.7 Accuracy assessment

Different metrics for accuracy evaluation of derived forest inventory variables are presented in Table 18.

Table 18: Accuracy of results of some main variables

Description	No. of stems (>=5 cm)/ha	Basal area (m^2/ha)	Stem volume (m^3/ha)	Air-dry biomass (t/ha)	Carbon stock (t/ha)	SVWB up to 10 cm top dia.	SVWB up to 20 cm top dia.
Mean	**615.9**	**20.9**	**200.9**	**232.5**	**99.4**	**148.4**	**125.9**
Standard Error	35.9	0.6	7.8	9.7	4.1	6.4	6.5
% of Error of Mean	5.8	3.1	3.9	4.2	4.2	4.3	5.2
% of Error of Mean at 95% CI	**11.4**	**6.0**	**7.7**	**8.1**	**8.1**	**8.5**	**10.2**
Lower limit at 95% CI	545.5	19.6	185.5	213.6	91.2	139.9	115.7
Upper limit at 95% CI	686.2	22.1	216.2	251.4	107.5	156.9	136.1

CI = confidence interval; dia = diameter; SVWB = Stem volume without bark

A separate accuracy assessment of the forest cover maps of Terai was not done as they were derived as a spatial subset of the national land cover map.

3.3 Terai Forest Soils

3.3.1. Soil Organic Carbon in Terai Forest

The total carbon in the soil component is 18.58 tg, equivalent to 68.14 tg CO_2 with an average rate of 47.38 tons per hectare (Table 19).

Table 19: Soil Organic Carbon (SOC)

Soil	
Carbon (t/ha)	47.38*
Total Carbon in the Terai (ton)	18,584,088.26
Total Carbon in soil component (tg)	18.58
Total CO_2 equivalent in soil component (tg)	68.14

* with standard deviation of 23.12 t/ha

3.3.2. Carbon content of Litter and Debris in Terai Forest

The total carbon in the litter and debris component is 0.13 tg, equivalent to 0.50 tg CO_2 with an average rate of 0.35 tons per hectare (Table 20).

Table 20: Carbon content in Litter and Debris

Litter and Debris	
Carbon (t/ha)	0.35**
Total Carbon in the Terai (ton)	135,427.55
Total Carbon in soil component (tg)	0.13
Total CO_2 equivalent in soil component (tg)	0.50

** with standard deviation of 0.21 t/ha

3.4. Carbon Stock in the Terai Forests

The above-ground carbon was estimated by multiplying estimated biomass by a conversion factor of 0.47, as recommended by the IPCC (IPCC, 2006) while CO_2 equivalent was estimated by multiplying carbon by a conversion factor of 44/12, as recommended by the Alabama Forestry Commission (n.d.). The carbon stock of tree component in the Terai forest is 50.83 tg (129.60 t/ha). Similarly, carbon stock of litter-debris and soil components are 0.13 tg (0.35 t/ha) and 18.58 tg (47.38 t/ha) respectively. Total carbon stock in the three major carbon pools of Terai forests is 69.54 tg (177.33 t/ha) (Table 21).

Table 21: Carbon stock in the Terai forests

Tree component	
Carbon (t/ha)	129.60
Total Carbon in ton	50834304
Total Carbon in tree component (tg)	50.83
Litter and Debris	
Carbon (t/ha)	0.35
Total Carbon in ton	135427.55
Total Carbon in litter and debris component (tg)	0.13
Soil	
Carbon (t/ha)	47.38
Total Carbon in ton	18584088.26
Total Carbon in soil component (tg)	18.58
Total Carbon in Terai forests (tg)	69.55 (177.33 t/ha)

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Annex-1: Summary of diameter-height model

SN	Species	Code	a	b	SE (a)	SE(b)
1	Sal	6615	1.7493705	0.1608696	0.03940878	0.00150497
2	Asna	6660	2.0158098	0.1512975	0.08463225	0.00249096
3	Banjhi/Dhauti	6113	1.7417515	0.1624742	0.11068057	0.00472418
4	Botdhangero	6369	1.8078193	0.1707381	0.1010265	0.0056485
5	Gutel	6676	2.2404575	0.1959194	0.3314945	0.0137124
6	Jamun	6651	2.4293770	0.1743042	0.26361435	0.00713541
7	Karma	6089	2.4615952	0.1586035	0.24028084	0.00556813
8	Khair	6063	2.0539346	0.1916212	0.25970422	0.01222871
9	Sirish	6098, 6100, 6103, 6104, 6105	2.1597717	0.1550531	0.3701565	0.0119723
10	Sissoo	6239	2.0559705	0.1624158	0.2745317	0.0148035
11	Bhurkul	6349	1.4327347	0.1916671	0.11774934	0.00826614
12	Jhingad	6370	2.0738437	0.1796699	0.18789470	0.00630533
13	Barro/Harro	6662/6664	1.9038921	0.1626262	0.14869740	0.00427842
14	Bel	6090	1.5878738	0.2381453	0.5966131	0.0229674
15	Tantari	6250	2.3244190	0.1785263	0.20608157	0.00676228
16	Miscellaneous		2.0483763	0.1896783	0.05846392	0.00281812

Annex-2: Derivation of volume ratio for trees having broken top

v = vf * (vcut.int/vtot.int),

where:

v = predicted stem volume (dm^3)

vf = volume (dm^3) predicted using models of Sharma and Pukkala (1990) and total height predicted using the height generalisation model for FRA

vcut.int = stem volume (dm^3) from stump height (15 cm) to the cut point of tree

vtot.int = stem volume (dm^3) from stump height (15 cm) to the tip of tree

Also,

a1-a3 = parameters of correction polynomial

b1-b8 = parameters of the relative taper curve (population mean) model, i.e. so-called *Fibonacci curve*.