CHURIA FORESTS OF NEPAL

2022

Government of Nepal

Ministry of Forests and Environment

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Sub-Tropical Riverine Forest in Churia, Kavrepalanchowk District,

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Acknowledgements

As a continuation of the national forest resource assessment (FRA) implemented between 2010 and 2014, the Government of Nepal initiated the remeasurement of FRA permanent sample plots in 2016. The field measurement of permanent sample plots (PSPs) in Churia was done in 2018 under the supervision of Forest Inventory and Carbon Measurement section with the help of hired individual experts for field work.

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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
DoF	Department of Forests
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%, includingthe 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 71% (1,345,929 ha) and 1.97% (37,251 ha), respectively, of the total area of the Churia physiographic region (1,895,607 ha). Thus, forest and OWL together cover 72.97% of the total area in the region.

Growing Stock

- The Churia forest contains a total of 957.18 million (711.17 per ha) live stems (≥ 5cm DBH). The number of standing dead stems (≥ 5cm DBH) was 41.47 million (30.81 per ha).
- The stem volume for live trees in the Churia forest is 222.53 million m^3 (165.34 m^3/ha).
- The main tree species in terms of proportion of stem volume are Sal (*Shorea robusta*) with 77.93 m^3/ha, followed by Asna (*Terminalia alata*) with 25.53 m^3/ha.
- The timber volumes without bark up to 10 cm top and up to 20 cm top diameters in the Churia forest are 114.28 m^3/ha and 91.61 m^3/ha.
- The Churia forest contained 259.34 t/ha of air-dry biomass, equivalent to 235.767 t/ha of oven-dry biomass.

Carbon stock

The Churia forest contains 215.47 million t C (**160.09** t/ha) of carbon stock.

Disturbances

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

Executive Summary

This report presents the results of a forest resource assessment carried out in the Churia physiographic region of Nepal between 2016 and 2018. In the previous forest resource assessment 477 permanent sample plots (PSPs) were established in 2012 and 2013 and out of those established PSPs, this assessment remeasured 469 PSPs. 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 1,895,607 ha of land in the Churia physiographic region, 'forest' and 'other wooded land (OWL)' covered 71% (1,345,929 ha) and 1.97% (37,251 ha), respectively. Thus, forest and OWL together covered 72.97% of the total area in the region.

The assessment reveals that the Churia forest contained a total of 957.18 million (711.17per ha) live stems (≥ 5cm DBH). Similarly, the number of standing dead stems (≥ 5cm DBH) is 41.47 million (30.81 per ha). The stem volume in the Churia forest is 165.34 m^3/ha. The main tree species in terms of proportion of stem volume are Sal (*Shorea robusta*) with 77.93 m^3/ha, followed by Asna (*Terminalia alata*) with 25.53 m^3/ha. The timber volumes without bark up to 10 cm top and up to 20 cm top diameters are 114.28 m3/ha and 91.61 m3/ha respectively.

The Churia forest contains 259.34 t/ha of air-dry biomass, equivalent to 235.767t/ha of oven-dry biomass. Similarly, it contains 160.09 t/ha of carbon stock. During the assessment, livestock grazing, tree cutting, and forest fire were the top three disturbances in the Churia 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 Churia forests between 2010 and 2012 (DFRS, 2014). The project had established 477 permanent sample plots (PSPs) in 109 clusters in the Churia forests for the periodic measurement of various forest parameters. These PSPs were measured in 2012. This report presents 1) the Churia forest statistics based on the measurement of a total of 469 plots between 2017 and 2018, and 2) the area statistics of the Churia forests based on the National Land Cover Monitoring System (FRTC, 2022).

1.2. The Environment of the Churia Forests

The term "Churia" refers to the Churia Physiographic Region of Nepal. The Churia, also known as the Siwalik, is the youngest mountain range in the Himalayas. Just north of the Terai, it runs the entire length of southern Nepal, from east to west, skirting the southern flanks of the Himalayas. The geology of the Churia is tectonic in origin and its rocks comprise north-dipping, semi-consolidated, interbedded tertiary sandstone, siltstone, shale and conglomerate (LRMP, 1986). While different studies have delineated the Churia region differently, this study considered it to extend from 80° 9′ 25″ to 88° 11′ 16″ longitudes and from 26° 37′ 47″ to 29° 10′ 27″ latitudes based on LRMP (Figure 1).

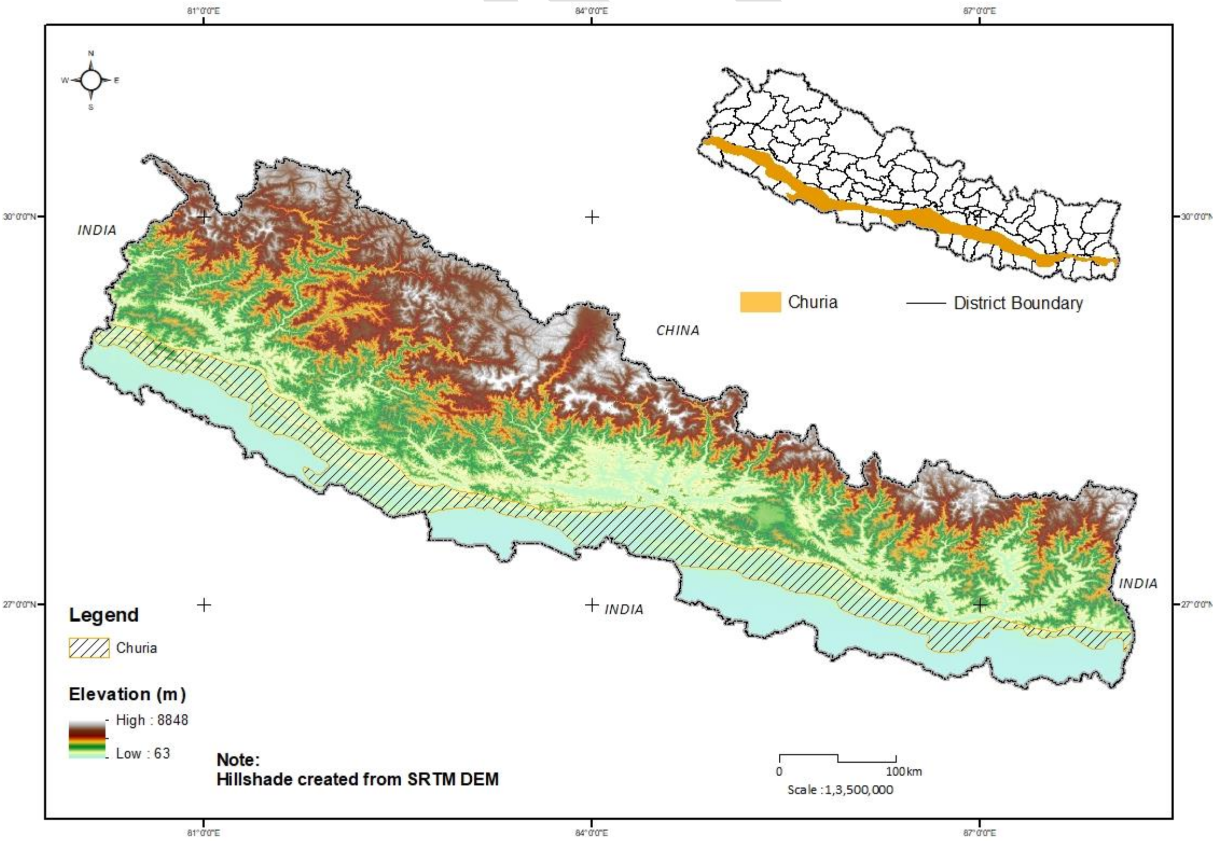

Figure 1 : The spatial extent of the Churia in Nepal

The elevation of the Churia varies from 93 to 1,955 meters above sea level and has a stretches of 10-50 km in width. Because the Churia is geologically speaking, the youngest mountain chain of the Himalaya, it is the most erodible and fragile.

Soils

The Churia hills are geologically young. Their soils originated from soft rocks. The lower Churia is largely composed of very fine-grained sediments such as variegated mudstone, siltstone and shale with smaller amounts of fine-grained sandstone (Upreti, 1999). The middle Churia has thick beds of multi-storied sandstones alternating with subordinate beds of mudstone. The upper Churia is characterized by very coarse sediments such as loose boulder conglomerates. The soils of the Churia are associated with land system 4-active and recent alluvial plains; land system 5-fans, aprons and ancient river terraces; land system 6-depositional basins (Dun valleys); land system 7-moderately to steeply sloping terrains; and locations.

Climate

The climate of the Churia region ranges from subtropical to warm temperate and is characterized by hot and sub-humid summers, intense monsoon rain, and cold dry winters. The average annual minimum temperature ranges from 12° C to 19° C; with the average annual maximum temperature ranging from 22° C to 30° C in this region. The precipitation pattern in the Churia is variable, with the highest annual rainfall in the Eastern and Central development regions.

Drainage

Several large rivers originating in the High Himal cut the east-west Churia chain, while smaller, ephemeral rivers flow only during the monsoon. Water in the small rivers may dry up totally outside the monsoon season, probably because the soil in the riverbeds is highly permeable (Shrestha et al., 2008). The Churia region is the origin of third-grade Rivers of Nepal. These rivers are characterized by their smaller sizes and low to almost no flow during the dry seasons. Flash floods commonly occur during monsoon season in these rivers and carry huge sediment loads to be deposited in the flood plains of the Terai. Bakra, Balan, Khutti, Patharaiya, Tinua, Baikaiya, Ratu, Kamala, Sirsia, Manusmara, Banganga, Sunsari etc. are the major rivers that originate in the Churia.

1.3. Forest Resource Assessment (2010-2014)

The recent and most comprehensive nationwide forest resource assessment (FRA) was implemented between 2010 and 2014 under the FRA Nepal Project with technical and financial assistance from the Government of Finland. The FRA Nepal Project (2010-2014) to provide comprehensive, up-to-date national- level forest resource information for use in national forest policy development and strategic forestry sector decision-making. It used a well-established inventory design (the systematic sampling of cluster plots) and took into account national data needs as assessed in 2010. Four physiographic strata, i.e. the Terai, Churia, Middle Mountains, High Mountains and High Himal, were considered for the assessment. The assessment in the Churia physiographic region was carried out between 2011 and 2012 (DFRS, 2014).

CHAPTER 2: METHODOLOGY

2.1 Introduction

The forest resource assessment in the Churia included remeasurements 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).

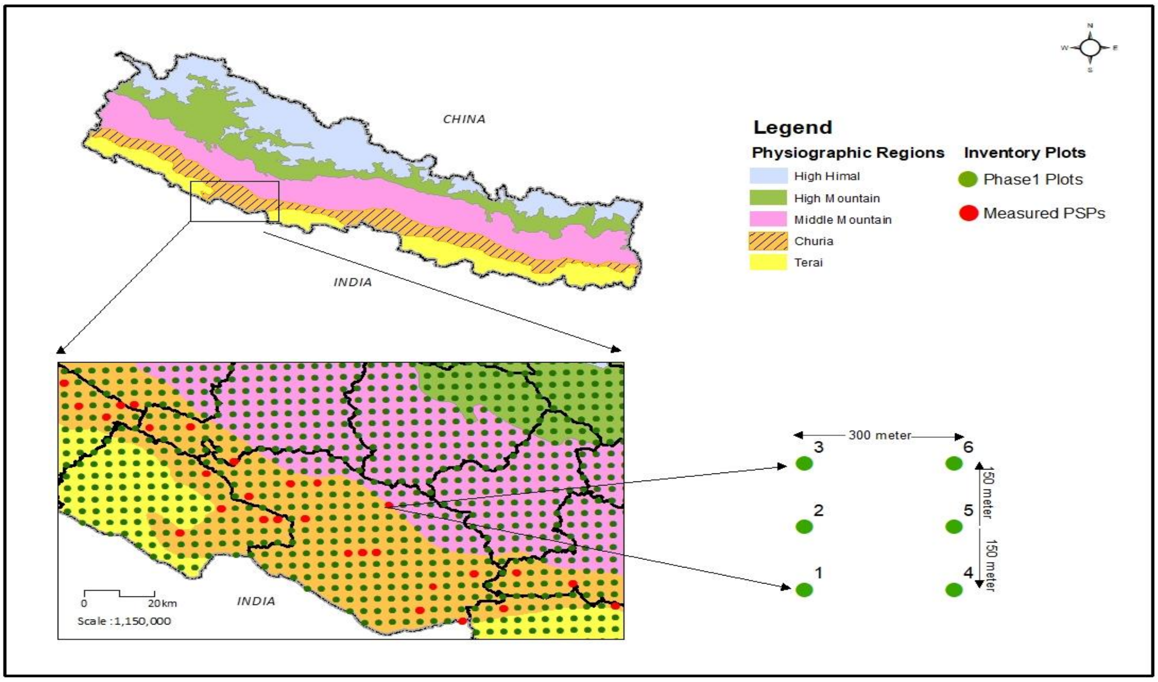

Figure 2 : Layout of the clusters and plot within each cluster[1].

The detailed methodology adopted for sample selection is presented in DFRS, 2014. Altogether 469 PSPs (107 clusters) were selected for this assessment (Figure 3).

[1] In Churia, each cluster consists of six plots.

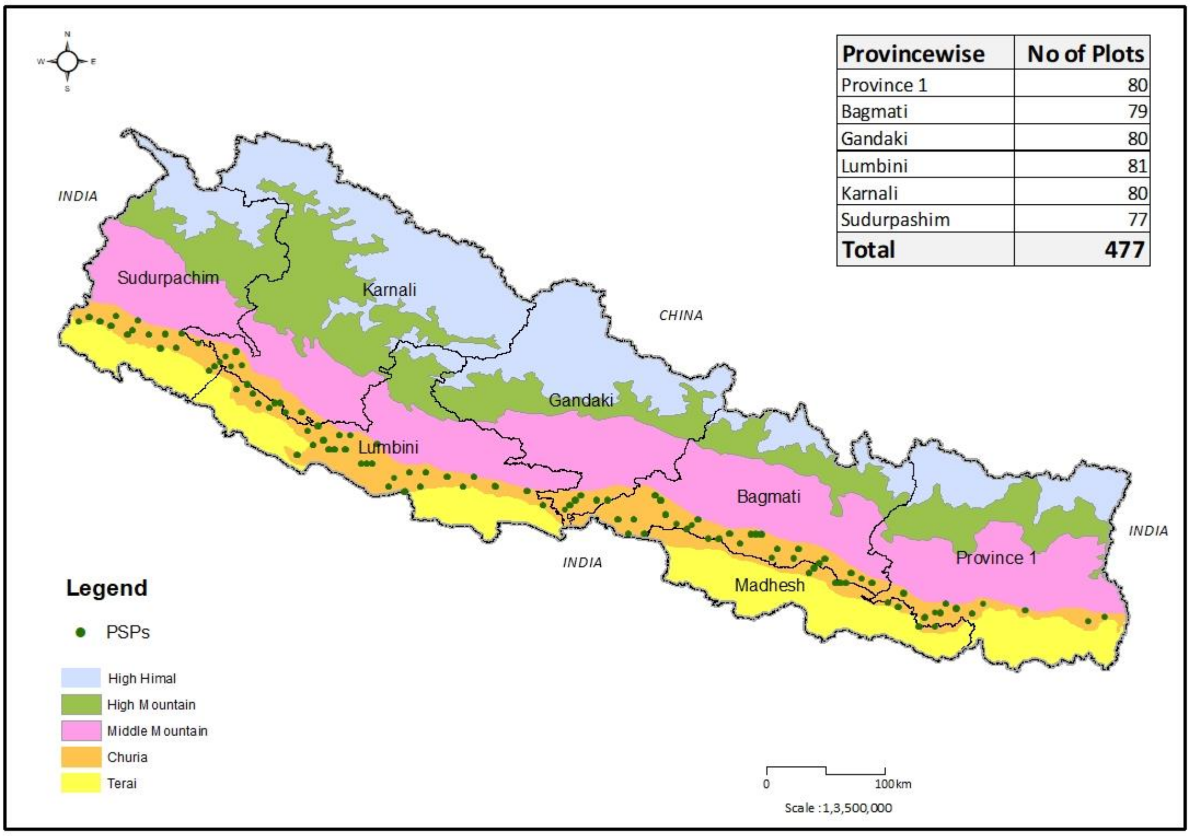

Figure 3 : The spatial distribution of measured permanent sample plots (PSPs).

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 4), 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.

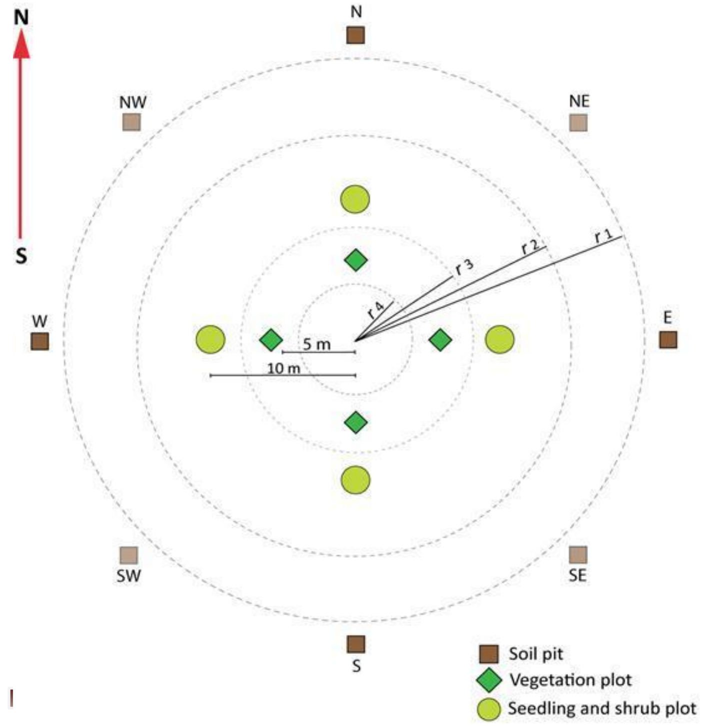

Figure 4: Layout of the concentric circular plot with other sub-plots

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 Churia 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

Total biomass = Stem biomass + branch biomass + 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 Churia 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 5).

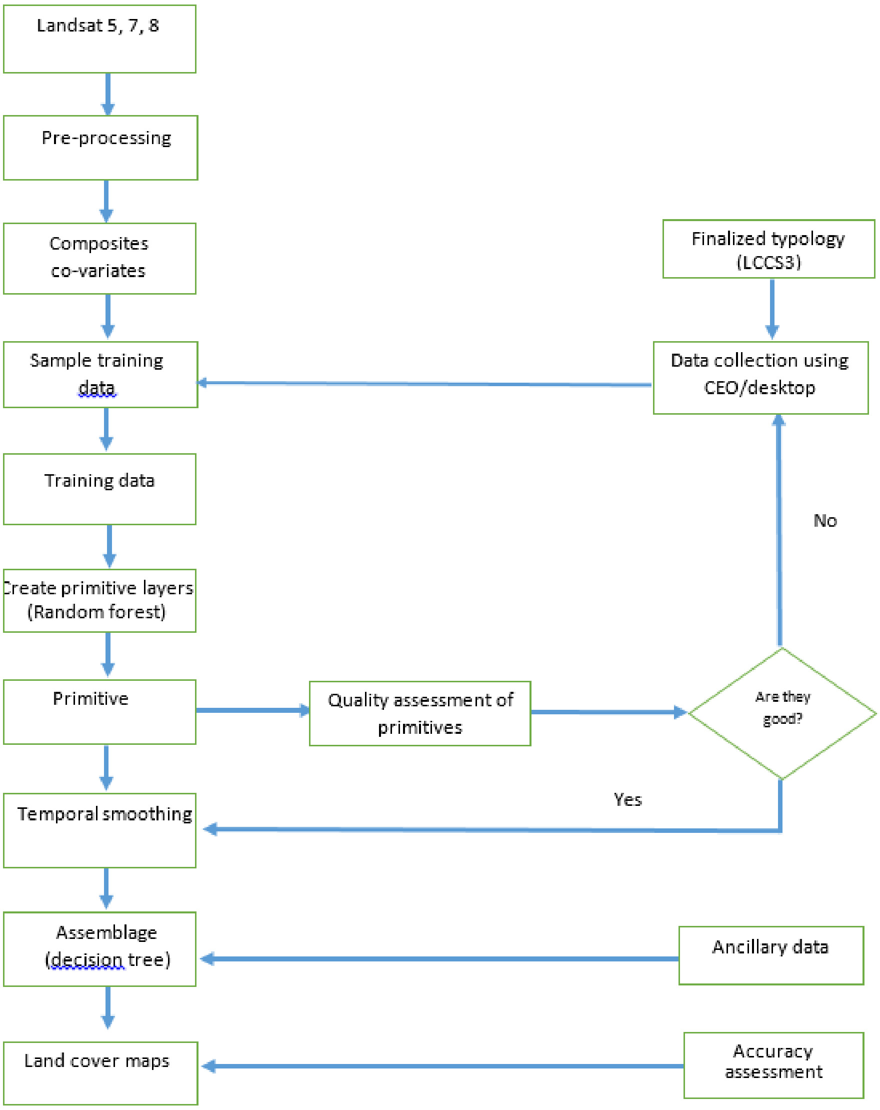

Figure 5: A flowchart showing the overall method of the NLCMS

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 6. 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 1 m^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 6). 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).

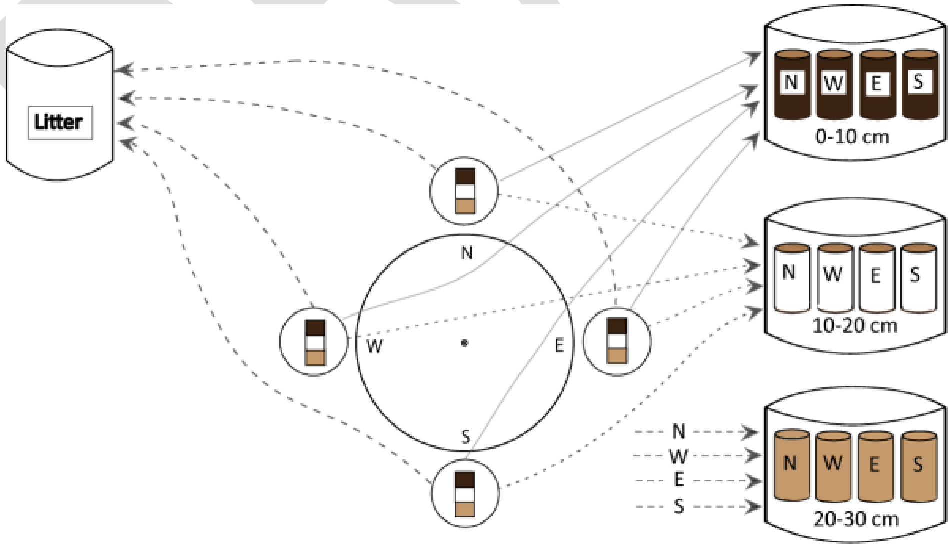

Figure 6: Collection of composite samples of litter, debris and soil from a plot

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 Churia 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 Churia 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 Churia 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 Churia Forest

Forest and Other Wooded Land (OWL) occupy 71 % (1345,929) and 1.97 % (37,251 ha) of the total area of the Churia Region, respectively. Thus, Forest and OWL together cover 72.97 % of the total land cover in the Churia (Table 4).

Table 4: Land cover in the Churia, 2019

Land cover class	Area	
	Ha	%
Forest	1345,929	71
Other Wooded Land (OWL)	37,251	1.97
Other land	512,427	27.03
Total	**189,5607**	

The land cover map of the Churia physiographic region is presented in Figure 7.

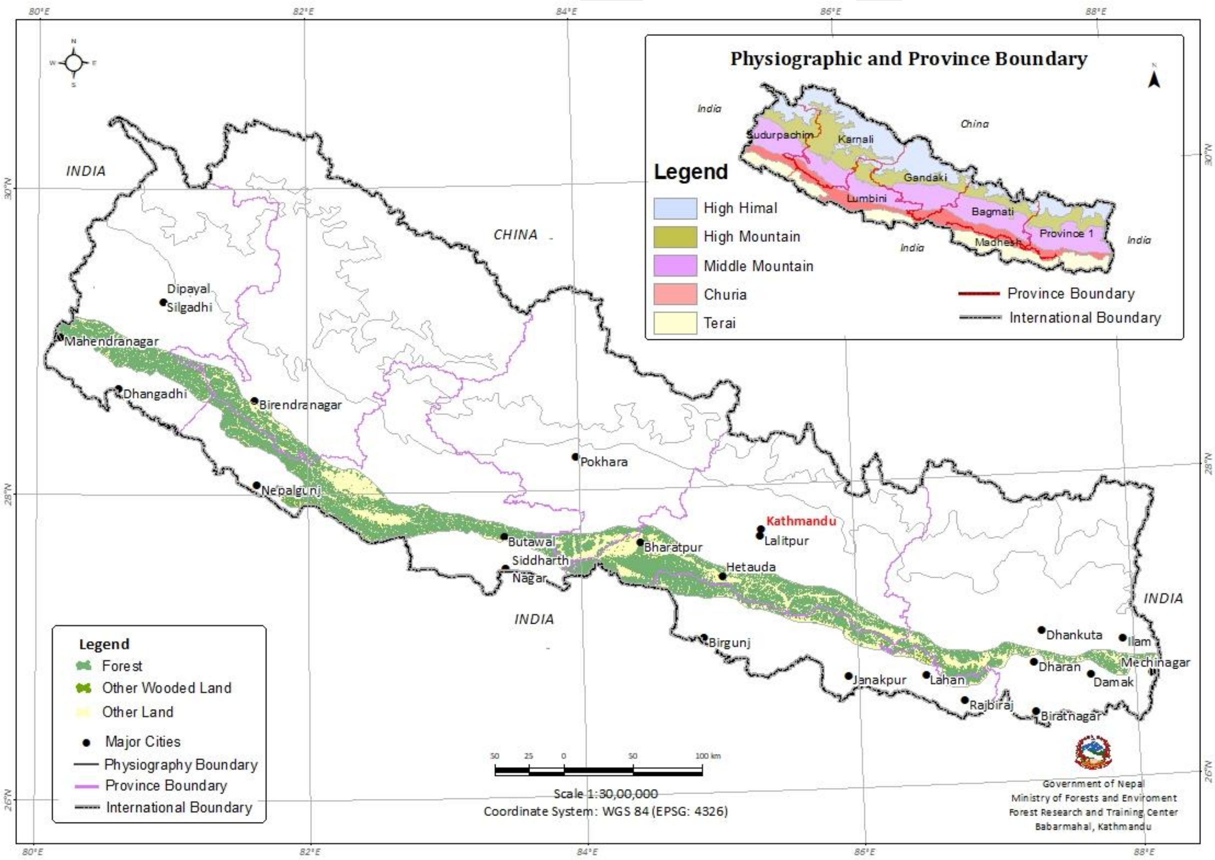

Figure 7: Land cover map of the Churia region, 2019

3.2. Churia 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 Churia forests are included in the result tables and graphs.

3.2.1 Number of stems (DBH>=5 cm)

The Churia forests of Nepal contain a total of 957.18 million live stems with DBH>=5cm, the average being 711.17 per hectare. There are 41.47 million standing dead stems (30.81 per hectare), of which more than 90 percent are usable. Co-dominant stems constitute the highest proportion of stems in the Churia forests, followed by dominant ones. About 18.38 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	203.39
	Co-dominant	217.22
	Intermediate	178.17
	Suppressed	54.16
	Understory	13.39
	Top-broken	44.85
Sub-total **(live stems)**		**711.17**
Standing dead stems	Dead usable	22.30
	Dead unusable	1.88
Sub-total **(standing dead stems)**		**30.81**
Stem removal (last five years)		**91.91**

Shorea robusta is the most abundant species in the Churia forests (212/ha), followed by *Terminalia alata* (52/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 351.05, 229.75, 62.95 and 49.98, respectively. The average weighted DBH and height of stems are 39.12 cm and 18.27 m, respectively, with *Adina cordifolia* having the largest ones (Average weighted DBH=61.35 cm and Average weighted height=23.47 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	*Shorea robusta*	87.20	71.12	19.40	24.65	9.63	211.99	43.31	19.98
2	*Terminalia alata*	25.45	12.20	4.68	6.26	3.91	52.49	52.95	23.14
3	*Adina cordifolia*	1.27	2.12	0.66	0.71	0.41	5.18	61.35	23.47
4	*Mallotus philippensis*	21.21	7.95	1.33	0.20	0.02	30.72	16.62	9.97
5	*Lagerstroemia parviflora*	15.27	10.93	3.08	1.65	0.15	31.08	26.59	15.83
6	*Anogeissus latifolia*	20.79	10.82	4.56	2.17	0.27	38.60	27.96	16.07
7	*Terminalia bellirica*	1.27	1.17	0.47	0.56	0.12	3.59	42.26	19.26

8	*Eugenia jambolana*	4.24	3.22	1.72	1.29	0.25	10.72	36.15	15.87
9	*Lannea coromandelica*	0.00	0.11	0.09	0.02	0.00	0.21	29.60	13.38
10	*Buchanania latifolia*	10.60	10.29	2.92	0.82	0.00	24.64	21.77	11.22
11	*Dillenia pentagyna*	1.27	1.70	0.45	0.34	0.03	3.80	28.47	13.96
12	*Acacia catechu*	2.12	2.86	1.12	0.41	0.02	6.53	24.94	13.32
13	*Pinus roxburghii*	2.12	3.71	1.44	1.16	0.55	8.98	44.51	24.07
14	Other species	158.22	91.56	21.04	9.73	2.09	282.65	29.43	13.96
	Total	**351.05**	**229.75**	**62.95**	**49.98**	**17.45**	**711.17**	**39.12**	**18.27 m**

The majority of stems (50.6%) in the Churia forests is in the quality class III, termed here as cull trees, and followed by sound trees (quality-II) with 26.8%. Only 22.6% of stems are classified as high-quality sound trees i.e. quality-I (Figure 8).

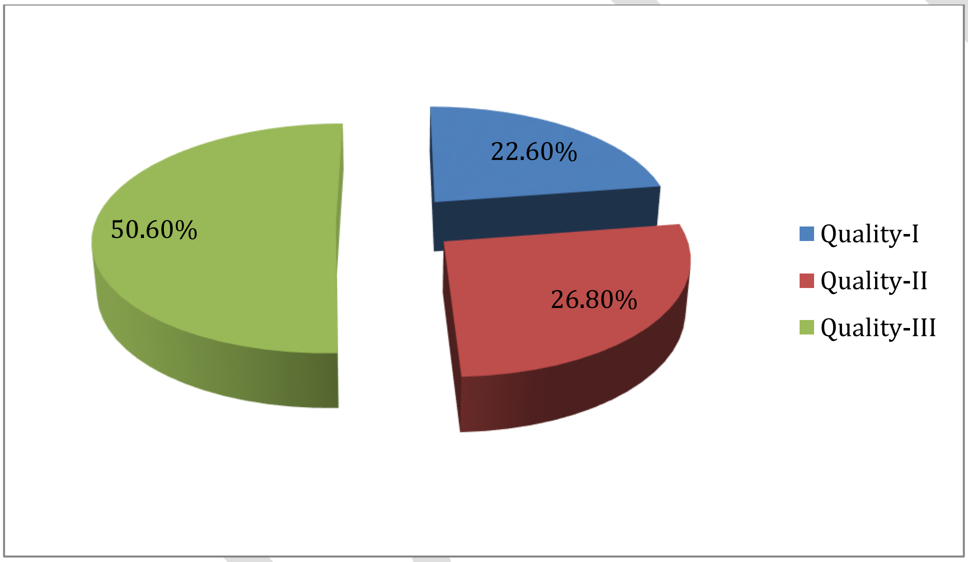

Figure 8: Number of stems by quality classes expressed as percentage

Shorea robusta, the most abundant and one of the most valuable timber-yielding species in the Churia, has the largest number of high-quality stems, with about 45.14% and 32.4% of its stems in quality-I and quality-II, respectively. However, more than 38.33% of stems of *Terminalia alata*, the second most abundant species in the Churia 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	*Shorea robusta*	95.69	68.79	47.51	211.99
2	*Terminalia alata*	17.73	14.64	20.12	52.49
3	*Adina cordifolia*	1.57	1.13	2.48	5.18

4	*Mallotus philippensis*	0.03	4.26	26.43	30.72
5	*Lagerstroemia parviflora*	5.24	8.08	17.76	31.08
6	*Anogeissus latifolia*	5.06	11.93	21.61	38.60
7	*Terminalia bellirica*	0.95	0.84	1.79	3.59
8	*Eugenia jambolana*	1.24	2.40	7.08	10.72
9	*Lannea coromandelica*	0.02	0.03	0.17	0.21
10	*Buchanania latifolia*	4.20	10.75	9.69	24.64
11	*Dillenia pentagyna*	0.07	1.54	2.19	3.80
12	*Acacia catechu*	1.67	2.05	2.81	6.53
13	*Pinus roxburghii*	5.63	1.73	1.62	8.98
14	Other species	21.10	62.61	198.94	282.65
	Total	**160.19**	**190.79**	**360.20**	**711.17**

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 Churia forests are 13,526 and 1,496 per hectare, respectively. Like the larger stems, *Shorea robusta* has the largest number of seedlings and saplings, followed by *Mallotus philippensis* (Table 8).

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

SN	Species	Seedling	Sapling	Total
1	*Acacia catechu*	57	16	73
2	*Adina cordifolia*	4	0	4
3	*Anogeissus latifolius*	191	51	242
4	*Buchanania latifolia*	448	0	448
5	*Dalbergia latifolia*	22	8	30
6	*Desmodium oojenense*	91	11	102
7	*Lagerstroemia parviflora*	75	56	131
8	*Mallotus philippensis*	241	68	309
9	*Pinus roxburghii*	37	5	42
10	*Schima wallichii*	28	26	54
11	*Shorea robusta*	7874	469	8343
12	*Syzygium cumini*	219	24	243
13	*Terminalia alata*	668	171	839

14	Others	3569	591	4160
	Total	**13,526**	**1,496**	**15022**

Regarding regeneration status in different forest types, *Shorea robusta* dominated both seedlings (3,595 /ha) and saplings (237/ha) in Sal forest. *Terminalia alata, Buchanania latifolia, Mallotus philippensis* and *Syzygium cumini* showed large regenerations per hectare. Regenerations of all the 14 species that contribute at least one percent to the total stem volume of the Churia forests are presented in Table 9. *In total, regenerations were highest in the Sal forests, followed by LMH, TMH, Pine and KS/SK forests. Regeneration in SK/KS forests was the lowest.*

Table 9: Number of seedlings and saplings per ha by species and forest types

SN	Species	Forest type									
		KS/SK		LMH		Pr		S		TMJH	
		Seedling	Sapling	Seedling	Sapling	Seedling	Sapling	Seedling	Sapling	Seedling	Sapling
1	*Acacia catechu*	2	3	0	0	0	0	3	3	53	11
2	*Adina cordifolia*	0	0	0	0	0	0	0	0	4	0
3	*Anogeissus latifolius*	0	1	10	1	0	0	29	14	152	35
4	*Buchanania latifolia*	0	0	0	0	0	0	207	0	240	0
5	*Dalbergia latifolia*	0	0	0	0	0	0	0	0	22	8
6	*Dalbergia sissoo*	0	0	0	0	0	0	0	0	0	0
7	*Desmodium oojenense*	3	0	8	2	0	0	14	0	67	9
8	*Lagerstroemia parviflora*	0	0	0	0	0	0	13	19	62	37
9	*Mallotus philippensis*	0	0	3	0	0	0	83	20	155	48
10	*Pinus roxburghii*	0	0	5	0	30	2	0	3	2	0
11	*Schima wallichii*	0	0	4	3	0	0	18	18	6	5
12	*Shorea robusta*	0	0	162	12	1	0	3595	237	4117	221
13	*Syzygium cumini*	0	0	2	1	10	0	80	7	127	16
14	*Terminalia alata*	0	0	16	6	0	0	209	50	443	115

Others	0	0	221	35	121	6	1342	220	1886	330
Total	**5**	**3**	**429**	**59**	**162**	**7**	**5595**	**593**	**7335**	**833**

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

The number of both seedlings and saplings were greatest in those forests with the highest crown covers. Likewise, the greatest number of seedlings was found in mature stands of large saw-timber while that of saplings was found in Seedling and sapling stand. Regeneration was the greatest in buffer zone forests followed by community forests, government-managed forests, PAs. It was least in private forests (Table 10).

Table 10: Number of seedlings and saplings by different forest attributes

SN	Forest attributes	No. of plots	Seedling	Sapling	Total
	Canopy cover				
1	< 40 %	52	11191	1370	**12560**
2	40-70 %	264	13400	1443	**14843**
3	> 70 %	153	14536	1631	**16166**
	Average	**469**	**13526**	**1496**	15022
	Development stage				
1	Seedling and sapling stand (< 12.5 cm DBH)	13	10774	2035	**12809**
2	Pole -timber stand (12.5 - 25.0 cm DBH)	137	11420	1641	**13061**
3	Small saw-timber stand (25.0 - 50.0 cm DBH)	222	12202	1446	**13648**
4	Large saw-timber stand (> 50.0 cm DBH)	97	19899	1333	**21232**
	Average	**469**	**13526**	**1496**	15022
	Management regime				
1	Private Forest	2	3780	497	**4277**
2	Government Managed Forest	94	12610	857	**13467**
3	Protected Forest (NP, WR etc.	76	9819	1259	**11078**
4	Bufferzone Forest (Govt. Managed)	3	18237	2719	**20955**
5	Bufferzone Forest (Community Forests)	23	21123	865	**21988**
	Community Forests	270	14311	1838	**16149**
	Others	1	0	0	**0**
	Average	469	13526	1496	15022

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

3.2.3 Basal area

The total basal area of live trees in the Churia forests was more than 19.83 m^2/ha, of which about two-thirds comprised of the dominant trees. The total basal areas of both standing dead trees and trees that had been removed (assessed by the presence of stumps) were minimal (Table 11).

Table 11: Basal area per ha by crown class

Status of stem	Crown class	Basal area m²/ha	Percent
Live stems	Dominant	12.58	63.47
	Co-dominant	4.17	21.03
	Intermediate	1.82	9.18
	Suppressed	0.48	2.42
	Understory	0.10	0.50
	Top-broken	0.67	3.38
Sub-total **(live stems)**		**19.83**	
Standing dead stems	Dead usable	0.60	
	Dead unusable	0.17	
Sub-total **(standing dead stems)**		**0.76**	
Stem removal (last 6 years)		**1.19****	
Dead Wood		**1.89**	

** *A six-year estimate*

Basal area per hectare was the highest (5.79 m^2) for diameter class 30-50. The second highest basal area (5.73 m^2 per ha) was in the diameter size greater than 50 cm, whereas the lowest basal area (1.58 m^2 per ha) was for saplings (5-10 cm). *Shorea robusta* had the largest basal area, approximately 43% of the total, followed by *Terminalia alata*, with approximately 13% (Table 12).

Table 12: Basal area per ha by species and DBH class

SN	Species	DBH (cm) class and basal area (m²/ha)					Total	Percent
		5-10	10-20	20-30	30-50	>50		
	Shorea robusta	0.41	1.15	0.96	2.93	3.02	8.48	42.8
	Terminalia alata	0.11	0.20	0.23	0.76	1.39	2.69	13.6
	Adina cordifolia	0.00	0.03	0.03	0.08	0.18	0.34	1.7
	Mallotus philippensis	0.10	0.12	0.06	0.02	0.01	0.31	1.6
	Lagerstroemia parviflora	0.07	0.19	0.14	0.18	0.04	0.63	3.2
	Anogeissus latifolia	0.09	0.18	0.22	0.23	0.07	0.79	4.0
	Terminalia bellirica	0.00	0.02	0.02	0.07	0.04	0.16	0.8
	Eugenia jambolana	0.02	0.06	0.09	0.14	0.08	0.38	1.9
	Lannea coromandelica	0.00	0.00	0.01	0.00	0.00	0.01	0.1
	Buchanania latifolia	0.05	0.17	0.13	0.09	0.00	0.44	2.2
	Dillenia pentagyna	0.01	0.03	0.02	0.04	0.01	0.10	0.5
	Acacia catechu	0.01	0.05	0.05	0.04	0.00	0.15	0.8

Pinus roxburghii	0.01	0.07	0.07	0.15	0.18	0.47	2.4
Other species	0.70	1.43	0.98	1.07	0.70	4.88	24.6
Total	**1.58**	**3.71**	**3.01**	**5.79**	**5.73**	**19.83**	**100**

3.2.4 Stem volume

The total volume of live stems (DBH >= 5 cm) in the Churia forests is 222.53 million m^3 (165.34 m^3/ha). Dominant stems constitute the highest proportion of stem volume (71%), followed by co-dominant ones (17.9%). The total volume of standing dead stems is 8.37 million m^3 (6.22 m^3/ha), of which more than 95 percent is usable. A total of 11.31 million m^3 (8.41 m^3/ha) of stem volume is estimated to have been removed in the last five years (Table 13).

Table 13: Stem volume per ha by crown class

Status of stem	Crown class	Stem volume(m^3/ha)	Stem volume/ha (%)
Live stems	Dominant	117.44	71.0
	Co-dominant	29.63	17.9
	Intermediate	10.61	6.4
	Suppressed	2.65	1.6
	Understory	0.46	0.3
	Top-broken	4.55	2.8
Sub-total **(live stems)**		**165.34**	**100**
Standing dead stems	Dead usable	5.03	
	Dead unusable	1.19	
Sub-total **(standing dead stems)**		**6.22**	
Stem removal (last six years)		**8.41****	

** A six year estimate

Based on forest types, Terai Mixed Hardwood forests had the greatest stem volume (96.97 m^3/ha), followed by Sal forests (58.08 m^3/ha). Khair-Sissoo forest had the least stem volume (0.08 m^3/ha) (Table 14).

Table 14: Stem volume based on forest type

Forest type	No. of sub-plots	Stem volume (m^3/ha)
Khair-Sissoo	2	0.08
Lower Mixed Hardwood	16	5.78
Chir Pine	11	4.44
Sal	132	58.08
Terai Mixed Hardwood	308	96.97
Total	**469**	**165.34**

In terms of DBH classes, the stem volume per hectare was 6.56 m^3/ha for saplings (5-10 cm), 22.69 m^3/ha for pole timber (10-20 cm), 75.80 m^3/ha for small saw-timber (20-50 cm), and 60.29 m^3/ha for mature trees (≥50 cm). *Shorea robusta* had the highest stem volume, approximately 47% of the total, followed by *Terminalia alata* with approximately 15%. In terms of stem size, the growing stock has increased with an increase in DBH class (Table 15).

Table 15: 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	*Shorea robusta*	1.81	7.84	8.15	28.06	32.08	77.93
2	*Terminalia alata*	0.43	1.30	1.87	7.20	14.73	25.53
3	*Adina cordifolia*	0.01	0.17	0.22	0.67	1.87	2.95
4	*Mallotus philippensis*	0.43	0.72	0.43	0.14	0.03	1.75
5	*Lagerstroemia parviflora*	0.29	1.18	1.12	1.57	0.38	4.54
6	*Anogeissus latifolia*	0.37	1.16	1.63	1.99	0.62	5.76
7	*Terminalia bellirica*	0.02	0.15	0.14	0.63	0.41	1.35
8	*Eugenia jambolana*	0.06	0.29	0.52	0.98	0.64	2.49
9	*Lannea coromandelica*	0.00	0.00	0.04	0.02	0.00	0.06
10	*Buchanania latifolia*	0.16	0.95	0.89	0.63	0.00	2.62
11	*Dillenia pentagyna*	0.02	0.17	0.14	0.28	0.07	0.69
12	*Acacia catechu*	0.03	0.23	0.36	0.29	0.03	0.94
13	*Pinus roxburghii*	0.04	0.45	0.62	1.78	2.62	5.51
14	Other species	2.90	8.08	6.84	8.58	6.81	33.21
	Total	**6.56**	**22.69**	**22.97**	**52.82**	**60.29**	**165.34**

High-quality sound trees (quality-I) have the largest contribution, 63 % of the total stem volume in the Churia forests, followed by sound trees (quality-II) and cull trees (quality-III), with 20% and 16%, respectively. Over 80% of the stem volume of *Shorea robusta* and *Terminalia alata*, the two most dominant species belong to quality-I stem (Table 16).

Table 16: 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	*Shorea robusta*	58.50	14.11	5.31	77.93
2	*Terminalia alata*	20.56	3.73	1.24	25.53
3	*Adina cordifolia*	1.89	0.72	0.34	2.95
4	*Mallotus philippensis*	0.02	0.42	1.31	1.75
5	*Largestermia parviflora*	1.78	1.56	1.20	4.54
6	*Anogeissus latifolia*	2.71	1.79	1.27	5.76

7	*Terminalia bellirica*	0.92	0.28	0.16	1.35
8	*Eugenia jambolana*	0.86	0.79	0.85	2.49
9	*Lannea coromandelica*	0.02	0.01	0.03	0.06
10	*Buchanania latifolia*	0.61	1.28	0.73	2.62
11	*Dillenia pentagyna*	0.09	0.33	0.27	0.69
12	*Acacia catechu*	0.32	0.41	0.21	0.94
13	*Pinus roxburghii*	5.29	0.13	0.10	5.51
14	Others	10.96	9.18	13.08	33.21
	Total	104.50	34.74	26.10	**165.34**

The total stem volume and volume of stems up to 10 cm top diameter and up to 20 cm top diameter without bark are 129.44, 114.28 and 91.61 cubic meters per hectare respectively (Table 17).

Table 17: 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	*Shorea robusta*	58.46	54.35	45.66
2	*Terminalia alata*	22.34	19.00	16.85
3	*Adina cordifolia*	2.28	2.17	1.97
4	*Mallotus philippensis*	1.29	0.78	0.33
5	*Lagerstroemia parviflora*	3.44	2.86	1.78
6	*Anogeissus latifolia*	5.11	4.34	2.80
7	*Terminalia bellirica*	1.14	1.06	0.88
8	*Eugenia jambolana*	1.89	1.68	1.29
9	*Lannea coromandelica*	0.05	0.04	0.03
10	*Buchanania latifolia*	2.04	1.63	0.87
11	*Dillenia pentagyna*	0.56	0.48	0.34
12	*Acacia catechu*	0.73	0.61	0.35
13	*Pinus roxburghii*	4.18	3.99	3.57
14	Other species	25.94	21.28	14.89
	Total	**129.44**	**114.28**	**91.61**

Stem volume without bark disaggregated by stem quality class and up to 10 and 20 cm top diameter is presented in Table 18.

Table 18 : 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	*Shorea robusta*	44.64	42.47	37.20	10.13	8.89	6.57	3.69	2.99	1.90
2	*Terminalia alata*	18.21	15.94	14.67	3.15	2.49	1.85	0.98	0.58	0.33
3	*Adina cordifolia*	1.47	1.43	1.32	0.56	0.54	0.51	0.25	0.20	0.13
4	*Mallotus philippensis*	0.02	0.02	0.01	0.32	0.24	0.09	0.95	0.52	0.23
5	*Largestermia parviflora*	1.41	1.28	0.89	1.19	1.00	0.58	0.85	0.58	0.30
6	*Anogeissus latifolia*	2.46	2.32	1.80	1.57	1.29	0.70	1.08	0.73	0.29
7	*Terminalia bellirica*	0.78	0.76	0.67	0.23	0.21	0.15	0.12	0.10	0.07
8	*Eugenia jambolana*	0.67	0.65	0.58	0.60	0.54	0.40	0.62	0.49	0.31
9	*Lannea coromandelica*	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02
10	*Buchanania latifolia*	0.49	0.41	0.26	1.00	0.81	0.44	0.56	0.41	0.17
11	*Dillenia pentagyna*	0.08	0.08	0.07	0.27	0.25	0.19	0.21	0.16	0.08
12	*Acacia catechu*	0.25	0.21	0.14	0.32	0.28	0.16	0.16	0.12	0.06
13	*Pinus roxburghii*	4.05	3.90	3.49	0.07	0.05	0.05	0.06	0.04	0.04
13	*Other species*	8.97	8.55	7.41	7.18	6.06	4.09	9.78	6.67	3.39
	Total	**104.5**	**102.3**	**94.2**	**29.7**	**27.1**	**20.9**	**24.7**	**19.0**	**10.7**

dia. = diameter

Regarding different management regimes, community forests hold the largest proportion in stem number, basal area and stem volume (Table 19).

Table 19: Stem volume (m3/ha) according to management regime

Management Regime	No of Plots	Number of stems/ Ha	Basal Area (Sq.m/Ha)	Stem volume (Cu.m./Ha)
Private forest	2	0.62	0.01	0.04
Government managed forest	94	143.73	3.82	30.94
Protected areas (NP, WLR, etc.)	76	109.23	3.58	29.95
Buffer zone (Govt. managed)	3	3.11	0.10	0.86
Buffer zone (Community managed)	23	33.36	0.95	8.35
Community forest	270	421.13	11.38	95.20
Other	1	0.00	0.00	0.00

3.2.5 Biomass

The Churia forests contain a total of 349.05 million tons of air-dry biomass (259.34 t/ha), equivalent to 317.32 million tons of oven-dry biomass (235.767t/ha). 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 (Table 20).

Table 20 : Biomass in the Churia forests (DBH>=5 cm)

Biomass components		Air-dry biomass (T/ha)
Aboveground	**Tree components**	
1. Live stems	Stem	136.94
	Branch	48.16
	Foliage	7.13
	Sub-total (a)	**192.23**
2. Dead stems	Stem	5.07
	Branch	1.12
	Foliage	0.00
	Sub-total (b)	**6.19**
3. Dead wood (c)		**9.05**
Total Aboveground biomass (AGB) (a+b+c)		**207.47**
Below ground biomass (BGB) (@ 25% of total AGB)		**51.87**
Total air-dry biomass (AGB + BGB)		**259.34**
Total oven-dry biomass (@ 90.90 % of the total air dry biomass)		**235.767**
Carbon (tree component>5cm dbh (M.ton/ha))		**110.810**

In terms of species, *Shorea robusta* contributes more than half of the total air-dry biomass of live trees, followed by *Terminalia alata* (Figure 9).

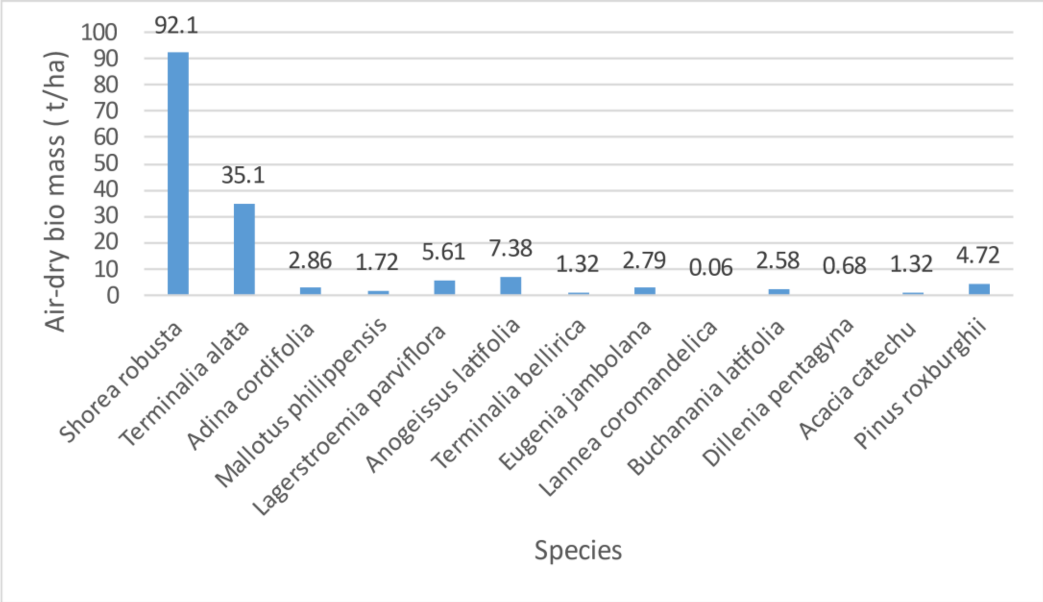

Figure 9: Aboveground biomass (air-dry) of live trees (DBH>=5cm) by species (t/ha)

3.2.6 Carbon stock

Total carbon stock in the three major carbon pools of Churia forests is 215.47 million t C. The average carbon stock in forest is **160.09** t/ha. Out of all, tree component contains about 80% while the litter and debris component represents less than 1 % (Table 21).

Table 21: Forest carbon stock in different pools

Carbon pool	Carbon stock (t/ha)
Tree component (=>5cm dbh)	110.810
Litter and debris	0.43
Soil organic carbon	48.85
Total carbon stock	**160.09**

3.2.7 Forest disturbances

Observing over 469 plots inside the Churia physiographic zone, 404 number of plots were found disturbed by multiple sources of disturbances. The livestock grazing (LG) disturbance was observed in the maximum number of plots (342) whereas wind/storm (WI) and plant disease (PD) were observed in the least number of plots (16 each) (Figure 10).

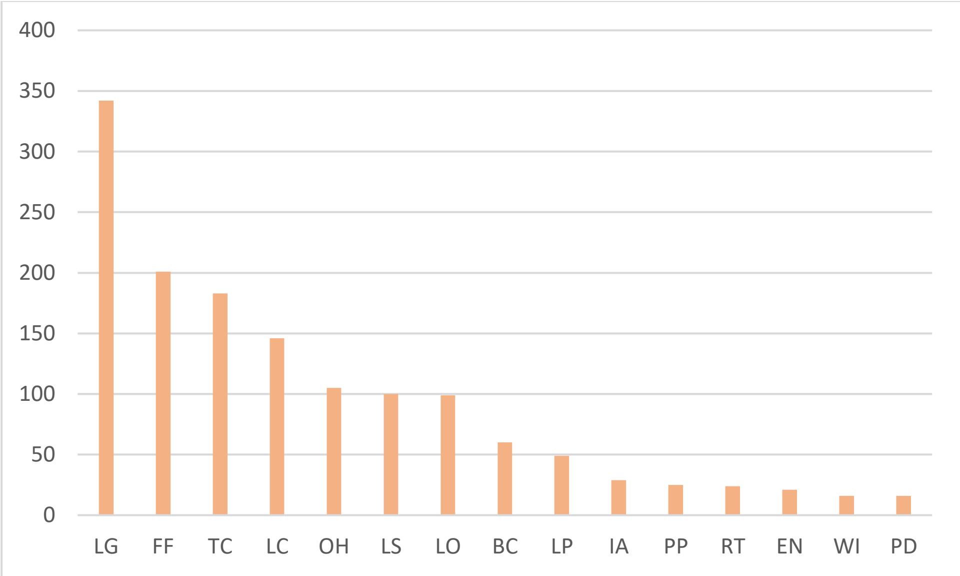

Figure 10: Occurrence of forest disturbances

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 11).

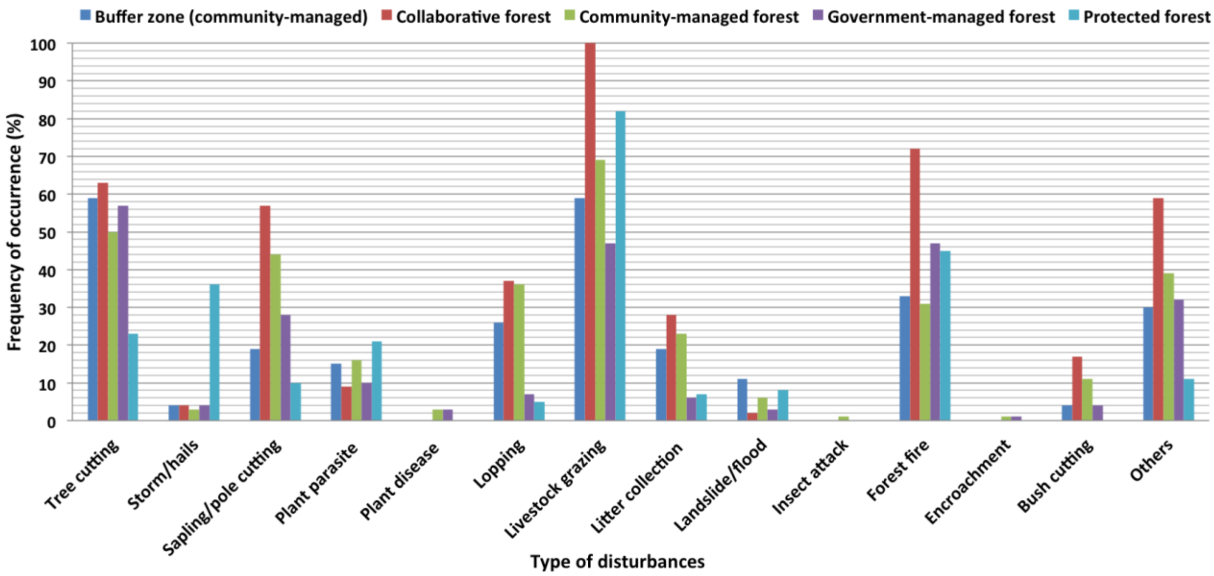

Figure 11: Occurrence of forest disturbances by forest management regimes

3.2.8 Accuracy assessment

Different metrices for accuracy evaluation of derived forest inventory variables are presented in Table 22.

Table 22: 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	**711.17**	**19.83**	**165.34**	**192.23**	**82.13**	**114.28**	**91.61**
Standard Error	36.35	0.61	6.17	7.48	3.20	4.86	4.73
% of Error of Mean	5.11	3.08	3.73	3.89	3.89	4.25	5.16
% of Error of Mean at 95% CI	10.02	6.04	7.31	7.63	7.63	8.34	10.12
Lower limit at 95% CI	639.93	18.63	153.25	177.57	75.87	104.75	82.34
Upper limit at 95% CI	782.42	21.03	177.43	206.89	88.40	123.81	100.88

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

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

References

Altrell, D., Branthomme, A., and Tavani, R. n.d. Assessing Growing Stock and Stock Changes through Multi-purpose National Forest Monitoring and Assessment. www.fao.org/forestry/26100-03805443a729838ab9172b9f1b989b1ca.doc, accessed on December 2, 2021.

Chaturvedi, A. N. 1982. Forest Mensuration. International Book Distributors, Dehradun, India.

Cochran, W. G. 1977. Sampling Techniques (3rd ed.). New York. John Wiley and Sons, Inc.

DFRS (2014). Churia Forests of Nepal (2010 – 2012). Babarmahal, Kathmandu: Forest Resource Assessment Nepal Project/Department of Forest Research and Survey.

FAO ,2006. Guidelines for soil description (4th ed.). Food and Agriculture Organisation of the United Nations, Publishing Management Service, Information Division, Rome, Italy.

FRTC, 2022. National Land Cover Monitoring System of Nepal. Forest Research and Training Centre (FRTC). Kathmandu, Nepal

Gering, L. R. 1995. The Relationship of Diameter at Breast Height and Crown Diameter for Four Species Groups in Hardin County, Tennessee. *Southern Journal of Applied Forestry*, Vol. 19 (4).

Heinonen, J., Saramaki, J. and Sekeli, P. M. 1996. A Polynomial Taper Curve Function for Zambian Exotic Tree Plantations. Journal of Tropical Forest Science, 8 (3): 339–354

IPCC, 2006. Good Practice Guidance for National Greenhouse Inventories. Agriculture, Forestry and Other Land Uses (Vol. 4). Geneva, Switzerland.

Jackson, J. K. 1994. Manual of Afforestation in Nepal. Nepal-United Kingdom Forestry Research Project. Forest Survey and Research Office, Department of Forests, Kathmandu, Nepal.

Kharal, D. K. and Fujiwara, T. 2012. Growth and yield estimation of *Chamaecyparis spp*. through tree ring analysis. Banko Janakari 22 (2): 36-42.

Kleinn, C. 1994. Forest Resources Inventories in Nepal Status, Quo, Needs, Recommendations. FRISP, HMGN/FINNIDA.

LRMP, 1986. Land System Report, Land Resource Mapping Project: Kenting Earth Science, Canada.

Mehtatalo Lauri and Kansanen Kasper (2020). lmfor: Functions for Forest Biometrics. R package version 1.5. https://CRAN.R-project.org/package=lmfor

MFSC 1988. Master Plan for the Forestry Sector in Nepal. Kathmandu, Nepal.

Pribyl, D. W. 2010. A Critical Review of the Conventional SOC to SOM conversion factor. Geoderma, 156: 75-83.

Sharma, E. R. and Pukkala, T. 1990. Volume Equations and Biomass Prediction of Forest Trees of Nepal (Publication No. 47). Kathmandu, Nepal: Forest Survey and Statistics Division, Kathmandu.

Survey Department. 2001. National Topographical Base Maps. Kathmandu, Nepal.

Upreti, B. N. 1999. An overview of the stratigraphy and tectonics of the Nepal Himalaya. Journal of Asian Earth Sciences 17: 577– 606.

Walkley, A. and Black, I. A. 1934. An Examination of the Degtjareff Method for Determining Organic Carbon in Soils: Effect of Variations in Digestion Conditions and of Inorganic Soil Constituents. Soil Science, 63:251-263.

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*.