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AN ASSESSMENT OF TREE SPECIES DIVERSITY, VOLUME AND ABOVE GROUND CARBON STOCK IN TREES OUTSIDE FORESTS (TOFS) (A CASE STUDY FROM POKHARA METROPOLITAN CITY, KASKI, NEPAL)

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A B S T R A C T

This study in Nepal evaluated Trees Outside Forests (TOFs), underscoring their diverse species composition and substantial carbon storage contributions. The research employed stratified random sampling across different TOF categories, revealing significant biomass distribution and carbon stocks, with notable species like Michelia champaca and Dalbergia sissoo showing high biomass and carbon densities. Diversity indices indicated highest diversity in scattered TOFs. The findings stress the importance of including TOFs in national and provincial inventories to enhance carbon management strategies and biodiversity conservation efforts, advocating for broader recognition and integration of TOFs in environmental policies and practices.

1. INTRODUCTION

1.1 Background

The concept of "Trees Outside Forests" emerged in 1995 to designate trees growing outside the forest and not belonging to forest or other wooded land. Trees Outside Forests (TOFs) are found in lands not defined as forest and other wooded land and generally includes trees on farmlands, in cities and human settlement, orchards, sides of roads, pastures, riverbanks, streams and canal and as shelterbelts which are less than 20 m wide and 0.5 ha area (FRA, 2020). Together, Nepal's forest and shrub land cover around 44.74% of the nation's total land area (DFRS/MoFSC, 2015). (FAO, 2010) established several standards for defining a forest, including 0.5 ha or more of land with trees that are at least 5 meters tall and have a canopy cover of at least 10%, or trees that can naturally reach these standards. TOFs encompass a wide range of formations and species that develop in a variety of combinations in both rural and urban environments (Acharya, 2006). In rural regions of both established and developing countries, the presence of trees on farms is a component of both traditional and modern agricultural practices (Baral et al., 2013). Trees Outside Forests contribute to economic, environmental and social wellbeing in places where there have never been forests or forest has disappeared (Mather, 2003). Forest and Trees Outside Forests are large carbon pools, sources as well as potential carbon sinks and sources to the atmosphere which play an important role in the global carbon cycle (Rawat et al., 1998). TOF are trees that grow on farms,

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common lands, wastelands, along highways, railroad tracks, and in institutions (Chakravarty et al., 2019). For a longer period of time, people have managed TOFs in the form of agroforestry systems and urban plantings (Abdulmalik et al., 2020). The resources that nature provides on earth are interdependent with life on the planet. As a result natural resources are the main ornament (Yadav et al., 2020). Tree resource whether it is inside the forest or outside the forest is one of the key components of natural resources because it performs several functions. Some vital functions are ecological importance, biodiversity conservation and carbon sequestration (Kumar, 2006). Trees Outside Forest performs two major categories of functions. They are productive and protective functions. Production of fruits and timber, fuel, and feed in orchards, fields, and other agroforestry systems are more particular, productive functions of TOFs. Similarly, protective functions include ecological and beautifying the environment, such as the placement of trees in parks, cities, and urban areas, as well as surrounding individual homes (Yadav et al., 2020; Thapa & Kelly 2017). Trees Outside Forests (TOFs) include formations of trees ranging from a single distinct tree to a group of trees that are carefully managed in agroforestry systems. Since TOFs is rarely used in natural resource evaluation, especially over broad areas, this topic has only lately become an important study problem (Schnell, Kleinn & Ståhl 2015). For its appraisal, a variety of factors need to be taken into account. First of all, this resource is dynamic and shows quick spatial and temporal changes as the socio-economic and cultural circumstances in which it is used change. Secondly, TOFs evaluation requires a unique design due to its very heterogeneous and dispersed configuration and distribution. Thirdly, the type of land tenure where TOFs is present varies and affects numerous entities and agencies. Before designing, there must be more discussion. Fourthly, the assessment fee has to be objective justification of the information's worth for policy 4 and development reasons. Due of the variety of challenges, TOFs is typically disregarded in resource allocation assessment, thus its impact on the area's ecology and economy has mostly persisted under or not recorded at all. Trees outside of the forest have been crucial in supplying the local population's demand for forest produce due to the decline of forest resources. To meet their demand for forest products and to generate extra revenue, residents in Nepal have begun growing a lot of trees on their private property (Rawat et al., 2004). The importance of forestry and agroforestry systems for the movement and long-term storage of carbon (C) in the terrestrial biosphere has raised interest in these land-use options to reduce greenhouse gas (GHG) emissions worldwide (Dixon et al., 1994). Consequently, TOFs in agroforestry systems has become more significant in the context of climate change in order to reduce and retain atmospheric carbon through improved development of trees and shrubs (Mehraj, et al. 2022). TOFs offer alternative sources for forest products, contributing in the conservation of forests by reducing reliance on their resources. TOFs are extremely valuable where forest resource is few and local people have limited access to them. Therefore, TOFs are developing into an integral component of the agro-ecosystem, which adds to the symbiotic relationships between producing crops and fauna (Omomowo & Babalol 2021). This practice is put into practice in several terai districts of Nepal (Yadav et al., 2017) but it is rarely practiced in mid-hills of Nepal. Anywhere in the world, including mid-hills of Nepal, planting trees as TOFs accomplishes ecological functions including carbon sequestration (Singh & Chand, 2012). However, researches on tree species diversity, volume and carbon stock have not been completed in Trees Outside Forests. This study is conducted with the goal of evaluating the tree species diversity, volume and carbon stock in TOFs.

1.2 Objectives

1.2.1 General objectives

The general objective of this study was to identify the tree species diversity, growing stock and quantify the carbon stock of Trees Outside Forests.

1.2.2 Specific objectives

The specific objectives of this research were:

1) To identify the types of TOFs categories in Pokhara Metropolitan city.
2) To calculate the species wise carbon stock of Trees Outside Forests.
3) To estimate the volume of the TOFs.
4) To calculate the tree species diversity of TOFs.

1.3 Hypothesis

1) Null hypothesis **(H0):** There is no significant difference in carbon stock among group, scattered and linear strata.
2) Alternative hypothesis **(H1):** There is significant difference in carbon stock among group, scattered and linear strata.

2. LITERATURE REVIEW

2.1 Trees Outside Forests

Food & Agricultural Organization (FAO 2020) of United Nations defines forest as land with a tree canopy cover of more than 10% and area of more than 0.5 ha. Forest is determined not only by the presence of trees but also by the absence of other predominant land uses (FAO, 2020). Thus, according to FAO, timber and rubber wood plantations are classified as forests but fruit orchards and trees planted under agro-forestry system are categorized as other lands with Trees Outside Forests. The majority of tree resources are associated with forests; however every country also possesses significant tree diversity outside of permanently wooded areas (Heyojoo & Nandy, 2015). Trees outside forests (TOFs) are found on farmland, in cities and human settlements, orchards, sides of highways, meadows, riverbanks, streams, and canals, and as shelterbelts. TOFs (Trees Outside Forests) improves economic, environmental and social well-being in areas where forest have never existed or forest have disappeared (Mather, 2003). TOFs is becoming increasingly extensively acknowledged as a strategy for biodiversity conservation, carbon sequestration, climate stability, and supporting rural and urban livelihoods (Acharya, 2006). TOFs are characterized as scattered, isolated or paddock trees in agricultural environment (Solomon, Mjöfors & Tersmeden 2020). Street and roadside trees, trees planted in parks, gardens, and private yards are examples of TOFs in cities and towns (Tyrvainen et al., 2005).

TOFs are increasingly recognized as an important element of either agricultural lands or built-up regions, according to many studies (Dida et al., 2015). Trees planted in parks, gardens, and private yards in cities and towns are considered to be part of the TOFs (Tyrvainen et al., 2005). Little is known about the factors that affect the spatial distribution of TOFs in urbanized or agricultural areas since they are frequently not taken into account in forest surveys (Rossi et al., 2016). According to a classification based on how forests and woodlands are categorized, TOFs are trees on land that is not classed as a forest or other wooded area (de Foresta et al., 2013). TOFs includes a variety of ecological processes, such as carbon sequestration and biodiversity conservation (Rawat et al., 2004).They improve soil organic carbon production in addition to storing a significant amount of carbon in live biomass (Follain et al., 2007). Time-consuming inventorying techniques make it difficult to implement management policies due to the absence of information on TOFs in official statistics (Yadav et al., 2017). Due to their huge carbon reservoirs and their capacity as both carbon producers and sinks, forests and trees outside of forests are crucial to the world cycle of carbon (Malhi, Meir & Brown 2002).

2.2 Carbon Sequestration

Carbon is the main component of all cell life forms. Trees utilize carbon as a building material to form stems, root, branches and leaves. Trees remove carbon from the environment through photosynthesis, extracting carbon-dioxide (CO2) from the air, isolating the carbon atom from the oxygen atoms and returning oxygen to the environment (Chalot et al., 2013). The term “carbon sequestration” is used to explain natural and intentional methods through which CO2 is eliminated from the atmosphere and stored within the terrestrial environments, oceans and geological formations (Co, 2012). Carbon sequestration is the method of removing additional carbon from the atmosphere and depositing it in different reservoir basically through change in land use (Mandal & Laake 2005). This process of transferring of carbon in the air into soil carbon, long term storage of carbon in the terrestrial biosphere, oceans reduces the build-up of carbon dioxide concentration in the atmosphere will be reduced. Removal of greenhouse gases from the atmosphere into sinks (i.e soil and vegetation) is one way of addressing climate change (Shrestha & Singh, 2008).

Carbon sequestration in terrestrial ecosystems, particularly soil, is a win–win strategy for developing countries, where land use change and agricultural intensification are common (Shrestha & Singh, 2008). Carbon sequestration function of forest is intimately related to the production function of forests (i.e the growth rate of trees). In the simplest case, if bare land such as agricultural lands are reforested it is clear that there is a large accumulation of carbon in above ground tree biomass (Mandal & Laake 2005). Afforestation program also play a major role to accelerate carbon sequestration and storage function (Hodgman et al. 2012). Forest occupies 4.03 billion hectares worldwide and occupies about 30 % of the world’s total area (FAO, 2020). Isolating atmospheric carbon by increasing the amount of plantation forests on earth has been suggested to be an effective measure to reduce atmospheric carbon dioxide (Peichl & Arain, 2006). Forests are the largest terrestrial carbon sink; deforestation and forest degradation result in carbon emissions from forests, which have an impact on the ecology and biodiversity in the tropics (FAO, 2020). Forest deforestation produces roughly 5.9 Gigatons of CO2 to the atmosphere each year (Solomon et al., 2007) and halting it can reduce CO2 emissions by 17.4% (IPPC, 2009). An additional 87 to 130 Gigatons carbon of CO2 is estimated to release in the atmosphere by 2100 if the current rate of deforestation continues (Gaudel et al., 2016). Degradation of forest resources has been one of the century's biggest issues. According to (Bhattacharyya et al., 2016), deforestation and forest degradation alone are responsible for 17.4% of global greenhouse gas emissions where carbon reserves are depleting at an alarming rate of 1-2 billion tons per year in tropical and subtropical forests, the issue is severe (Bhattacharyya et al., 2016). Forests have been suggested as a potential ecological form measurement to combat climate change because deforestation contributes to it (Bonan 2008; Agrawal, Nepstad & Chhatre 2011).

3. MATERIALS AND METHODS

3.1 Geographic Overview of the study area

The present research was carried out in the existing Trees Outside Forests of ward number 17 of Pokhara Metropolitan city of Kaski district. Kaski district lies in province 4 of Nepal. It lies in 28° 06' to 28° 36' N latitude and 83° 40' to 84° 12' E longitude. The area of Kaski district is 2,017 km^2. Similarly the area of Pokhara Metropolitan city is 464.2 km2 whereas the area of ward number 17 is 790 hectare. The types of climate found in this district are sub-tropical, temperate, temperate cold alpine and tundra climate. Kaski district has high intensity of rainfall throughout the year in Nepal, and about 80% of rainfall occurs typically in four months; June, July, August and September. The lowest elevation point is 450 meter and highest elevation point is 8091 meter from mean sea level of the district. Some tree species found in this area are *Cinnamomum camphora*, *Dalbergia sissoo*, *Bombax ceiba*, *Schima wallichi*, *Cassia fistula*, etc. The district is full of rivers such as Seti Gandaki, Modi and Madi along with other rivulets. The George of Seti River, Davis Falls, natural caves, Fewa Lake, Begnas Lake, Rupa Lake, etc are the main tourists attraction. The district has one metropolitan city, 4 rural municipalities and 3 electrol sectors (Figure 1). The district is one of the richest districts from biodiversity point of view. The primary goal for choosing this ward was because no appropriate research related to TOFs variety and carbon stocks were made in this region. Different types of land use are covered in this area. Many people have started roadside plantations and planted many species of trees on their farmlands which made this area more suitable for the study and important from the perspective of carbon sequestration.

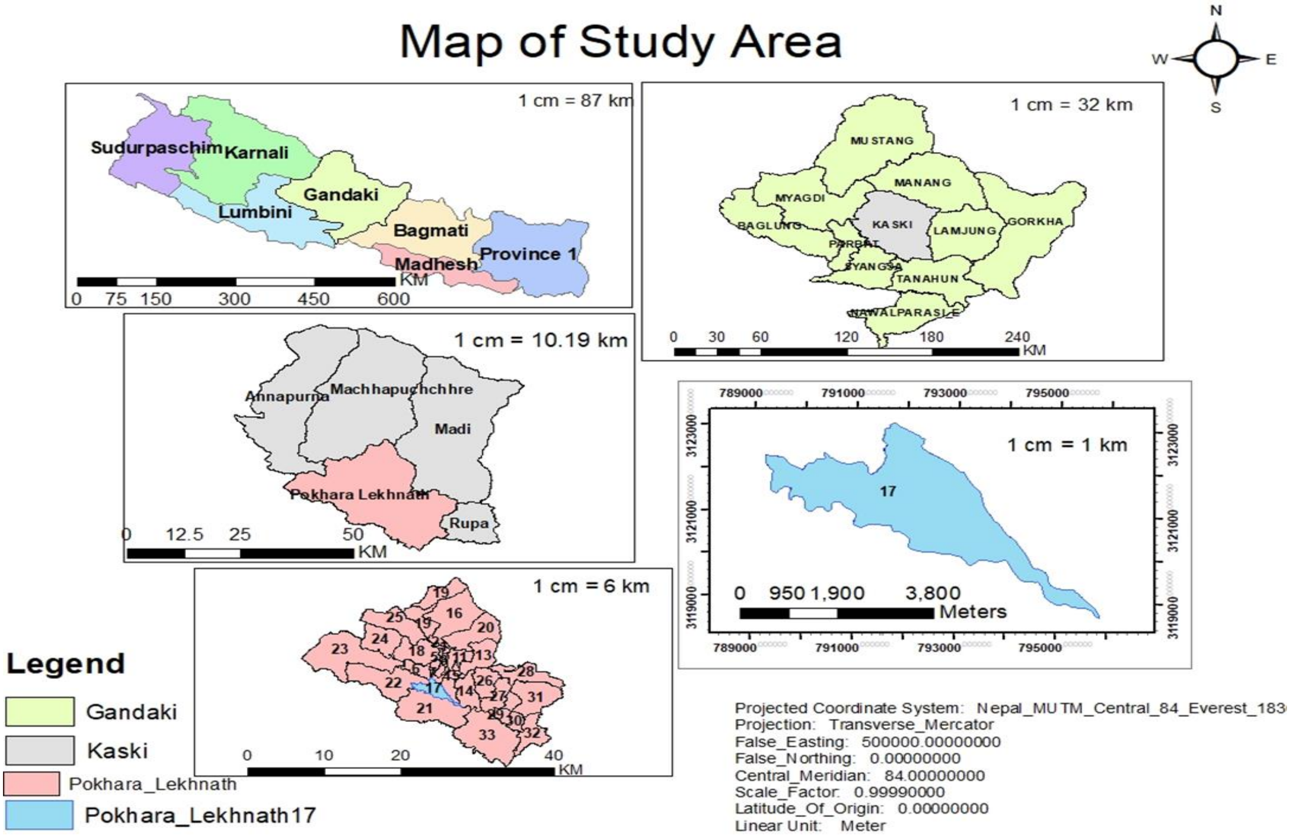

Figure 1. Map of study area

3.2 Status of TOFs in the study area

People living in this area follow the traditional farming system. Paddy field is the dominant land use in this area .On the bunds of paddy field, people plant fodder species such as *Dalbergia sissoo*, *Schima wallichi*,*Cinnamomum camphora*, *Prunus cerasoides* etc. Around house people practice the home garden farming system and cultivate fruit trees *like Magnifera indica*, *Psidium guava*, etc with fodder species. Along the highway people have planted ornamental plants such as *Cinnamomum tamala*, *Juniperusindica*, etc. However, scattered individual trees are the dominant pattern in TOFs configuration in this study area.

3.3 Reasons for choosing the study area

The reasons behind choosing ward number 17 of Pokhara Metropolitan city of Kaski district are:

- The area belongs to the urban area of western development region.
- The area is quite far from the forest area.
- Studies regarding tree species diversity and carbon stocks are not being made in adequate manner in this area.

3.4 Summary of the Materials

3.4.1 Global Positioning System

A Garmin GPS was used for recording and searching all the coordinates of the different ground points. For standard GPS, the expected accuracy of a handheld GPS receiver is +/-3m.

3.4.2 Other instruments and materials

Materials such as Clinometer, Diameter tape, linear tape, stick (1.3m) were used for the different purposes. For top and bottom angle measurement clinometer was used. Diameter tape was used for diameter measurement and linear tape for the sample plots layout. A stick of 1.3m was used for determining the diameter at breast height.

3.5 An Outline of Methodology

The study process began with the introduction of ideas for identifying the TOFs areas based on literature studies and the preparation of a formal scientific research proposal based on the idea created. Numerous opinions regarding the subject were obtained during the proposal development process from various experts and professionals through direct contact, telephone conversations, and emails. A number of conversations with the adviser gave rise to critical thought on the principles employed in this research. After consulting with the advisor and specialists, data were collected utilizing a variety of approaches. Following fieldwork, information from the field was discussed with the advisor and experts. In order to collect any missing data, a post-field visit was also conducted. The production of the final thesis was followed by the preparation of the conclusions and suggestions after data compilation, analysis, reporting, and discussions with the advisor.

3.6 Research Framework

The research framework is presented on the figure 2.

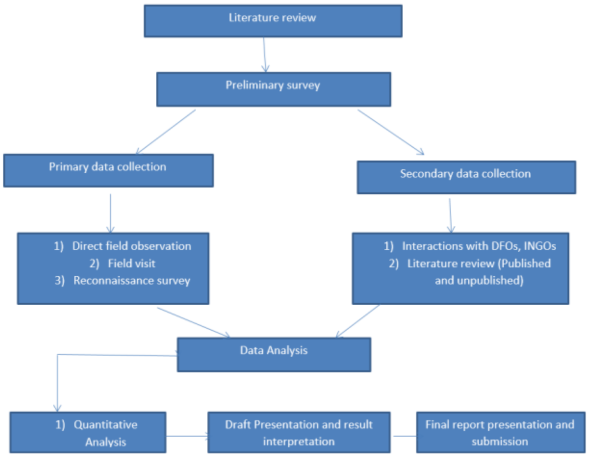

Figure 2. Research framework

All necessary steps are presented as well as their connections.

3.7 Sampling Design

An inventory of trees was required in order to gather the data on Trees Outside Forests (TOFs). Stratified Random Sampling was carried out for block, scattered and linear data as described by Forest Survey of India for TOFs inventory (FSI, 2011). Trees on parks, gardens, private plantations, etc were considered under group strata. Similarly, trees on farm lands, agricultural lands were considered under scattered strata and roadside plantations, canal side etc were taken under linear strata. Sampling Intensity of 1.5% was used for the TOFs strata excluding the forest area. Trees having crown cover >10% was considered as the 'Group' strata while less than 10% was considered as the 'Scattered' strata (Yadav et al., 2017). Different plots were established in different strata having 32m * 32 m for the block strata and 50m * 50m for scattered strata so that coverage represents the TOFs (FSI, 2011) and measurement was carried out.

3.7.1 Sample Plot Allocation

The tree cover of the study area was mapped using Arc GIS 10.4. Residential areas, agricultural land, and tree cover were all categorized. Using the shape file of the community woods in the area, the amount of forest was subtracted. Strata were divided and sample plots were allocated randomly on agriculture lands and tree cover areas. Along with this field survey was also carried for field verification of GIS data. Sentinal 2A image along with Google earth interpretation provided enough information about group TOFs but enough information about scattered TOFs couldn't be derived from the image as it needed high resolution image. So, from the field survey GPS points for the scattered plots were taken and entered in GIS. A total of 39 sample plots were allocated in group, scattered and linear strata. Firstly, map of the area was studied very carefully and then TOFs were identified as;

- In the group stratum: Stratified random sampling was applied to collect the data. The plot was established using GPS. Total 12 sample plots having plot size 32m*32m were applied in the field for group stratum of TOFs (FSI, 2011).
- In the scattered stratum: Stratified random sampling was applied to collect the data. The plot was established using GPS. Total 16 sample plots having plot size 50m*50m were applied in the field in scattered plantation of TOFs (FSI, 2011).
- In the linear stratum: Stratified random sampling was applied to collect the data. The plot was established using GPS. Total 11 sample plots having plot size 50 m * total width with plantation was applied in the field (FSI, 2011)

3.8 Data collection

3.8.1 Primary Data Collection

The primary data was collected through:

a) Reconnaissance Survey

A reconnaissance survey was carried out in the field. The study aimed at getting a better idea about land-use systems and TOFs distribution. It afforded us the opportunity to have prior discussions with the local villagers who have abundant information about the TOFs owners.

b) Biophysical data collection

Non-destructive approach was used for the biomass estimation and only trees above 10 cm DBH (Diameter at Breast Height) were measured. During the field work, local name of the tree were also recorded by the help of the staff and local people. 3.10.2 Secondary Data Collection Secondary data was collected through literature review of published and unpublished reports, books, and journals, internet, and discussion with various experts, forest officials & records from Ministry of Forests and Soil Conservation (MoFSC), Department of Forest (DoF), District Forest Office (DFO) and other concerning NGO's and INGO's and various other concerned agencies and office records, internet, guidelines, journals, magazines and other relevant sources.

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3.9 Data Analysis

Data collected from field survey was analyzed using different equations and formulas. MS Excel and Statistical Package for Social Science (SPSS) were also used in data analysis. Listing and categorization of TOFs was also done. Then the data was analyzed to get the result. Qualitative Data Analysis was done using descriptive analysis and the result was shown through tables, pie-charts and bar diagrams.Quantitative Data Analysis was done through ANOVA test.

3.9.1 Biomass Estimation

The biomass of tree includes all parts such as stem branch, root, leaves and undergrowth biomass.

Above Ground Tree Biomass (AGTB)

Above Ground Tree Biomass in kg (AGTB) = 0.0509*δ D2H (Chave et al., 2005).

Where,

AGB= above ground tree biomass (kg)

δ = dry wood density (g/cm3)

D= tree diameter at breast height (cm)

H= tree height (m)

3.9.2 Estimation of Carbon Content

Estimation of Carbon Content

Based on the results of different studies related to estimation of carbon in wood, it was observed that carbon varies between 45% and 50% for different ecosystems and thus considering 47.5% (IPCC default value) carbon in the woody biomass was quite reasonable for regional level carbon pool estimations.

The aboveground tree carbon (stem, branch and leaf carbon) was calculated using stock method.

Carbon %= 47% of total tree biomass (IPCC, 2006)

3.9.3 Volume Estimation

The volume of Trees Outside Forests is calculated by using the formula given below:

$$\text{Volume} = \frac{\pi D^2 \times h \times ff}{4}$$

Where,

π = 3.14

D= diameter at breast height (cm)

H= height of the tree (m)

ff= form factor that is 0.5 (DoF, 2003)

Tree per ha= Total number of tree in sample plot × 10,000

Total sample plot area

3.9.4 Tree Species Diversity Calculation

Tree Species Diversity Calculation

Species diversity was assessed using Shannon wiener diversity index (H') and Simpson's (D).The Shannon's diversity index is a statistical parameter, intended to measure the biodiversity of an ecosystem. The advantage of this index is that, it considers both the number of species or by having greater species evenness. Species diversity was estimated by using Shannon Wieners' Diversity Index (H'). The formulas are given below:

Shannon-Wiener Biodiversity Index (H') = -∑ Pi logpi (Carter, 2012).

Where, "H" represents the symbol for diversity in an ecosystem

Simpson's Biodiversity Index, (D) = 1- ∑ Pi

Where, Pi is the relative abundance of each species, i.e.; the proportion of individuals of a given species relative to the total no. of individual in the community.

D= Simpson Biodiversity Index

4. RESULTS AND DISCUSSION

4.1. Species wise biomass and carbon stock by stratum

4.1.1. Group Stratum

4.1.1.1 Distribution of above ground biomass by species in Group Stratum

It was found that the above ground biomass of *Michelia champaca* dominated all other species in group plantation with 9.24t/ha followed by *Dalbergia sissoo* with 6.2t/ha.*Prunus cerasoides* has 2.84t/ha while that of other species is quite below when compared. Distribution of AGTB and C (AGTB) by species is given in table 1 for group plantation and comparative representation of AGTB by species in group stratum is given in figure 3:

Table 1. Above Ground Tree Biomass (AGTB) and C (AGTB) of different species in group stratum

S.N	Species	AGTB(t/ha)	C(AGTB) t/ha
1	*Dalbergia sisoo*	6.242	2.93
2	*Cinnamomum camphora*	1.538	0.72
3	*Prunus cerasoides*	2.847	1.33
4	*Bombax ceiba*	0.146	0.06
5	*Magnolia champaca*	9.246	4.34
6	*Cinnamomum tamala*	0.328	0.15
7	*Magnifera indica*	0.08	0.03
8	*Diploknema butyracea*	0.15	0.07
	Total	**20.577**	**9.63**

4.1.2.2 Distribution of above ground carbon stock by species in group stratum

Carbon stock in above ground biomass also followed the same trend as that of above ground biomass. *Magnolia champaca* had the highest carbon stock in

AGTB with 4.34t/ha followed by *Dalbergia sissoo* and *Prunus cerasoides* with 2.93 and 1.33 ton per hectare respectively. Carbon stock in different species in group stratum is given in table 1 above and comparative representation of distribution of carbon stock by species is given in figure 3 below.

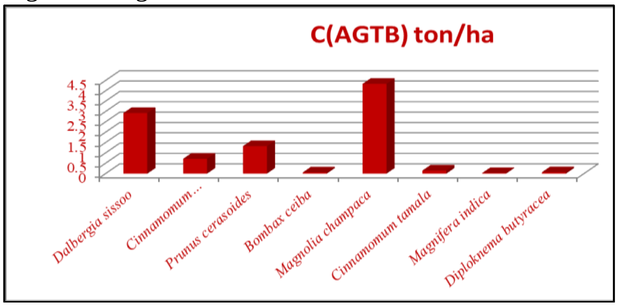

Figure 3. Distribution of C (AGTB) by species in Group stratum

4.1.2 Scattered Stratum

4.1.2.1 Distribution of above ground biomass by species in Scattered Stratum

It was found that the highest above ground biomass was of *Dalbergia sissoo* with 5.38t/ha followed by *Cassia fistula* with 2.95t/ha. From the study, it was found that the lowest above ground biomass was of *Choerospondias axillaris* with 0.02t/ha. The detail of distribution of AGTB is given in table 2 and is represented in figure 3 below.

Table 2. Above Ground Tree Biomass (AGTB) and C (AGTB) of different species in scattered stratum

S.N	Species	AGTB(t/ha)	C(AGTB) t/ha
1	*Dalbergia sissoo*	5.38	2.53
2	*Cassia fistula*	2.95	1.38
3	*Choerospondias axillaris*	0.02	0.01
4	*Bombax ceiba*	1.28	0.6
5	*Ficus religiosa*	1	0.47
6	*Ficus glaberrima*	0.26	0.12
7	*Bauhinia variegata*	0.04	0.01
8	*Delonix regia*	0.05	0.02
9	*Elaeocarpus ganitrus*	0.16	0.07
10	*Schima wallichi*	0.06	0.03
11	*Litchi chinensis*	0.35	0.16
12	*Prunus cerasoides*	0.75	0.35
13	*Erythrina arboescens*	0.04	0.01
14	*Cinnamomom tamala*	0.31	0.14
15	*Pyrus pyrifolia*	0.11	0.05
	Total	**12.76**	**5.95**

Distribution of above ground carbon stock by species in scattered stratum

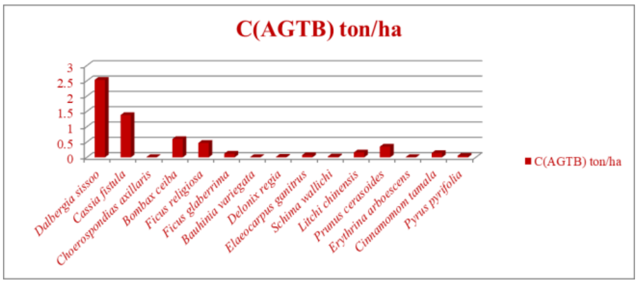

Figure 4. Distribution of C (AGTB) by species in Scattered stratum

Dalbergia sissoo dominated the above ground carbon stock in scattered stratum with 2.53 t/ha followed by *Cassia fistula* and *Bombax ceiba* with 1.38 and 0.6 t/ha respectively. Details about distribution of above ground carbon stock for different species in scattered stratum is given in table 2 and represented in figure 2.

4.1.3 Linear Stratum

4.1.3.1 Distribution of above ground biomass by species in Linear Stratum

From the study, it was found out that the highest above ground biomass was of Ficus bengalensis with 2.35t/ha followed by *Cassia fistula* with 1.06t/ha. The least above ground biomass was of *Cinnamomum tamala* with 0.14t/ha. The detail of distribution of AGTB is given in Table 3 and is represented in figure 3 below.

Table 3. Above Ground Tree Biomass (AGTB) and C (AGTB) of different species in linear stratum

S.N	Species	AGTB(t/ha)	C(AGTB) t/ha
1	*Cinnamomum camphora*	0.63	0.3
2	*Machilus odoratissima*	0.18	0.08
3	*Ficus bengalensis*	2.35	1.1
4	*Delonix regia*	0.66	0.31
5	*Saraca asoca*	0.38	0.18
6	*Cinnamomum tamala*	0.14	0.07
7	*Cassia fistula*	1.06	0.5
	Total	**5.4**	**2.54**

<u>Distribution of above ground carbon stock by species in linear stratum</u>

Carbon stock in above ground biomass also followed same trend as that of above ground biomass. *Ficus bengalensis* had the highest carbon stock with 1.1t/ha followed by *Cassia fistula* and *Cinnamomum tamala* with 0.5 and 0.07 t/ha respectively. Details about distribution of above ground carbon stock for different species in linear stratum is given in table 3 and represented in figure 5.

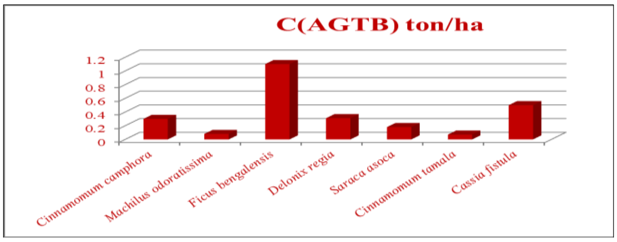

Figure 5. Distribution of C (AGTB) by species in Linear stratum

4.1.3 Distribution of Total Average carbon stock according to stratum

Table 5. ANOVA table for comparison of carbon stocks in different strata

Carbon Stock(t/ha)	Sum of Squares(SS)	Degree of freedom (df)	Mean Square (MS)	F statistic	P- value
Between groups	50.87	2	25.43	3.52	0.04
Within groups	202.32	28	7.22		
Total	**253.19**	**30**			

Since the P value for the F statistic is below 0.05, a one-way ANOVA was used to compare carbon stocks across different strata (Table 5). The analysis revealed a significant difference in carbon stock among the three strata F(2, 28) = 3.52, P = 0.04). Tukey's HSD test was then conducted to determine which strata significantly differed from each other.

Table 6. Tukey's HSD test result

Strata	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD interference
Group VS Scattered strata	3.52	0.04	P<0.05
Linear VS Group strata	3.02	0.09	Insignificant
Scattered VS Linear strata	3.02	0.89	Insignificant

Tukey's post hoc test revealed a significant difference in carbon stock between the group and scattered strata (p = 0.04). No significant differences were found between the linear and group strata (p = 0.09) or the scattered and linear strata (p = 0.08) (Table 6)..

4.1.4 Evaluation of volume of TOFs

The highest per hectare volume in the group stratum was found in *Michelia champaca* (90m³/ha), followed by *Dalbergia sissoo* (40.2m³/ha), with the lowest in *Magnifera indica* (0.87m³/ha).

Table 7. Linear stratum

S.N	Strata	Species	Volume(m³/ha)	Total volume
1	Group	1) *Michelia champaca* 2) *Dalbergia sissoo* 3) *Magnifera indica*	90 40.2 0.87	176.95
2	Scattered	1) *Dalbergia sissoo* 2) *Cassia fistula* 3) *Pyrus pyrifolia*	21.29 13.5 0.48	60.86
3	Linear	1) Cassis fistula 2) Ficus bengalensis 3) Cinnamomum tamala	34 30.71 4.57	133.64

In the scattered stratum, the highest per hectare volume was found in *Dalbergia sissoo* (21.29m³/ha), followed by *Cassia fistula* (13.5m³/ha), with the lowest in *Pyrus pyrifolia* (0.48m³/ha).

In the linear stratum, the highest per hectare volume was found in *Cassia fistula* (34m³/ha), followed by *Ficus bengalensis* (30.71m³/ha), with the lowest in *Cinnamomum tamala* (4.57m³/ha) (Table 7).

4.1.5 Tree Species Diversity in Group, Scattered and Linear Stratum

In the group stratum, 8 tree species were found (Table 7). The scattered stratum had 15 species, and the linear stratum had 7 species. Species richness depends on the abundance of each species. The scattered plantation showed higher tree diversity compared to group and linear strata.

Table 7. Group stratum

S.N	Strata	Species	Total species
1	Group	Dalbergia sissoo Cinnamomum camphora Prunus cerasoides Nyctanthes arbor tristis Bombax ceiba Michelia champaca Pinus roxburghii Cinnamomum tamala Ficus bengalensis	8
2	Scattered	Bombax ceiba Cassia fistula Choerospondias axillaris Dalbergia sissoo Ficus religiosa Ficus glaberrima Bauhinia purpurea Bauhinia variegata Delonix regia Elaeocarpus ganitrus Schima wallichi Persea americana Magnifera indica Litchi chinensis Prunus cerasoides	15
3	Linear	*Cinnamomum camphora* Cassia fistula Machilus odoratissima Ficus bengalensis Mimosa pudica Saraca asoca Ficus glaberrima	

5. DISCUSSION

5.1 Tree Species Diversity

This study assessed biodiversity in different strata, finding the highest diversity in scattered plantations with a Simpson's Index of 0.86 and Shannon Wiener

Index of 2.52. Yadav et al. (2020) and Pandey (2008) also noted greater tree species diversity in scattered plantations and community-managed forests, respectively. Common species include *Dalbergia sissoo* and *Melia azederach*. Home gardens are crucial for food self-sufficiency and biodiversity conservation. Nepal's forest policy prioritizes biodiversity conservation, with a significant focus on community forests in the Mid-Hills, which hold 32% of the country's forests and can store up to 48.60 t of carbon per hectare (Paudela et al., 2017). Effective management is essential to prevent biodiversity loss.

5.2 Tree biomass and carbon

The study found that carbon stock in the group stratum was higher than in scattered and linear strata. The above-ground tree biomass and carbon stock were highest in the group stratum, at about 20.57 tons/ha and 9.63 tons/ha, respectively. In the scattered stratum, these values were about 12.76 tons/ha and 5.95 tons/ha, and in the linear stratum, about 5.4 tons/ha and 2.54 tons/ha.

In the group stratum, *Magnolia champaca* had the highest carbon stock at 4.34 tons/ha, likely due to its high presence. In the scattered stratum, *Dalbergia sissoo* had the highest carbon stock at 2.53 tons/ha, while in the linear stratum, *Ficus bengalensis* had the highest at 1.1 tons/ha.

5.3 Volume

The study found that the greatest volume was in the group stratum, measuring 176.95 m³/ha. Following this, the linear stratum had the second highest volume at 133.64 m³/ha, while the scattered stratum had the least volume at 60.86 m³/ha.Among tree species, Magnolia champaca stored the highest volume in the group stratum (90 m³/ha), Dalbergia sissoo in the scattered stratum (21.29 m³/ha), and Cassia fistula in the linear stratum (34 m³/ha).

6. CONCLUSION

In the study area, 30 tree species were recorded: 8 in the group stratum including *Dalbergia* sissoo, Cinnamomum camphora, and *Magnifera indica*; 15 in the scattered stratum like Ficus *glaberrima*, *Bombax ceiba*, and *Cassia fistula*; and 7 in the linear stratum. Tree species diversity was highest in the scattered stratum and lowest in the group stratum.Volume-wise, the group stratum had the highest at 176.95 m³/ha, followed by the linear stratum at 133.64 m³/ha, and the scattered stratum with the least at 60.86 m³/ha. Magnolia champaca stored the most volume in the group stratum, *Dalbergia sissoo* in the scattered, and *Cassia fistula* in the linear stratum. Regarding carbon stock, the group stratum had the highest at 9.63 t/ha, compared to 5.95 t/ha in scattered and 2.5 t/ha in linear strata. Statistical analysis showed significant differences in carbon stock between group and scattered strata (p=0.04), but no significant differences between group and linear (p=0.09) or scattered and linear strata (p=0.08).

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