TREES OUTSIDE FORESTS

OF

KATHMANDU VALLEY

A THESIS SUBMITTED TO THE

CENTRAL DEPARTMENT OF BOTANY

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

NEPAL

FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

IN BOTANY

BY

BABITA SHRESTHA

May, 2023

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DEAN'S OFFICE

Kirtipur, Kathmandu, Nepal

Reference No.:

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Kirtipur, 2045

EXTERNAL EXAMINERS

The Title of Ph.D. Thesis: " Trees Outside Forests of Kathmandu Valley "

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November 3, 2023

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Asst. Dean

DECLARATION

This thesis entitled **"TREES OUTSIDE FORESTS OF KATHMANDU VALLEY"** which is being submitted to the Central Department of BOTANY, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by me under the supervision of Prof. Dr. Ram Kailash Prasad Yadav of Central Department of Botany, Tribhuvan University and co-supervised by Dr. Bhuvan Keshar Sharma, of Conservation Development Foundation Nepal (CODEFUND), Kathmandu, Nepal.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

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Babita Shrestha

RECOMMENDATION

This is to recommend that **Babita Shrestha** has carried out research entitled **"Trees outside Forests of Kathmandu Valley"** for the award of Doctor of Philosophy (Ph.D.) in **Botany** under our supervision. To our knowledge, this work has not been submitted for any other degree.

She has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D. degree.

....

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LETTER OF APPROVAL

Date: May 26, 2023

On the recommendation of **Prof. Dr. Ram Kailash Prasad Yadav** (Central Department of Botany, Tribhuvan University, Kathmandu) and **Dr. Bhuvan Keshar Sharma** (Conservation Development Foundation Nepal (CODEFUND), Kathmandu, Nepal), this Ph.D. thesis submitted by **Babita Shrestha** entitled **"Trees Outside Forests of Kathmandu Valley"** is forwarded by the Central Department Research Committee (CDRC) to the Dean, IOST, TU.

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Babita Shrestha

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ABSTRACT

Trees Outside Forests (hereafter TOFs) are one or more trees and or shrubs found in an area of <0.5 ha. These are found in all strata such as urban, suburban and rural. These are important for biodiversity conservation and carbon storage. Some TOFs serve as Tree Related Micro Habitats (hereafter TreMs) while some TOFs are important for timber production. All TOFs are important for firewood production. The broad objective of this research is to increase our knowledge in the field of TOFs by understanding biodiversity, carbon stock and ecosystem services provided by TOFs in urban-rural gradient in Kathmandu Valley. The specific objectives of the study are: to assess the species diversity of TOFs; to estimate the phytomass carbon stock and SOC of TOFs; to assess the ecosystem services (TreMs) provided by the TOFs and to assess the economic valuation (Timber and firewood) of TOFs.

This research was carried out in Kathmandu Valley. Data were collected from May 2015 to February 2017. Inventory was performed in 209 randomly selected points by MS Excel using circular plots of 20 m radius in all three strata. Tree level characteristics of TOFs (height > 1.37 m and DBH ≥ 5 cm) in the plots were recorded along with quality class. Other organisms making one or more habitats or support on the TOFs species were also enumerated. Nests and cavities if present were noted along with the organism types. Sap or resin if present were also recorded. Soil samples were also collected from five cordial pits in each plot. A comparative analysis of species richness, similarity index, species diversity index, evenness, maturity index, species richness index, species importance value index (IVI), family importance value (FIV), tree density, phytomass carbon stock, Soil Organic Carbon (hereafter SOC), Tree related Microhabitats (TreMs) along with quality class, wood production potential and timber and firewood values were done in TOFs along the urban–rural gradient in Kathmandu Valley.

A total of 6,210 individuals of 150 plant species [trees (n=121) and shrubs (n=29)] belonging to 111 genera and 57 families were recorded. These species came under 80 natives and 70 exotics. The average values of species number, species richness, Shannon-Weiner diversity index, evenness and Menhinick's species richness index were 6.32, 50.24 ha^{-1}, 1.33, 0.61, and 1.24 respectively in the study area. The average species richness was higher in the urban stratum (55.95 ha^{-1}). Similarity index was higher in urban-suburban (SI= 0.66) strata. The average Shannon Weiner diversity index was higher in the urban stratum (1.46). Average evenness was significantly higher in the urban stratum (0.67). The average Menhenick's species richness index was higher in the rural stratum (1.28). Maturity index of the study area was 4.39. It was higher in rural stratum (6.74). The average values of tree density, phytomass carbon stock and SOC in the study area were 236.35 ha^{-1}, 32.40 t ha^{-1} and 42.32 t ha^{-1}. Average tree density was found higher in the suburban stratum (248.44 ha^{-1}). Average species richness was found higher in the urban stratum (55.95 ha^{-1}). The suburban stratum was richer in native species (53.33 %). Similarly, average phytomass carbon stock was significantly higher in urban stratum (39.41 t ha^{-1}). But average SOC was higher in rural stratum (44.78 t ha^{-1}). One thousand and thirty-eight individuals of 64 species were found to serve as TreMs. Four forms, 5 groups and 14 types of TreMs were recorded in the study area. All types were found in urban stratum. Similarly, 53 tree species were recorded with merchantable timber in the study area. The average tree density of quality class A was significantly higher and that of quality class B was higher in the urban stratum. The average tree density of quality class C was higher in the suburban stratum. *Cinnamonum camphora* and *Pinus roxburghii* were found to have more market values for total timber and firewood respectively in the study area.

TOFs have diverged species richness in the study area. *C. camphora* was found to be the important TOFs species for carbon storage, TreMs along with higher merchantable value of total wood. The study provides the baseline data useful for biodiversity conservation through TOFs, urban green enhancement, green urban planning and development, carbon sink management, TreMs along with the useful timber species suggesting a need for appropriate species selection for TOFs plantations. *Gravillea robusta*, *C. camphora* & *P. roxburghii* with highest IVI values and carbon storing capacities should be planted on urban areas for greenery and to enhance the air quality & manage carbon in the atmosphere. More tree plantations in TOFs areas are recommended for timber availability which would upgrade the local livelihoods, to lessen the import of wood & wooden materials, increase the urban greenery and create better environment. More researches on TOFs that is kept under forestry should be done.

Keywords: IVI, merchantable timber, Shannon-Weiner diversity index, SOC, quality class, strata, tree density, TreMs.

सारांश

जंगल बाहिरका रुखहरु (TOFs) भन्नाले ०.५ हेक्टर क्षेत्रफलमा पाईने एक वा बढी रुख र वा झाडीहरुलाई जनाउँछ । यिनीहरु शहरी, अर्धशहरी तथा ग्रामिण सवै क्षेत्रमा पाईन्छन् । यिनीहरु जैविक बिविधता र त्यसको संरक्षण तथा कार्वन भण्डारणका लागि महत्वपूर्ण छन् । केही रुखहरुले सूक्ष्म बासस्थानको सेवा पनि प्रदान गर्दछन् भने केही रुखहरु काठ उत्पादनका लागि महत्वपूर्ण हुन्छन् । सबै प्रकारका रुखहरु दाउरा उत्पादनका लागि उपयुक्त हुन्छन् । यो अनुसन्धानको मुख्य उद्देश्य काठमाडौं उपत्यकाको शहरी देखि ग्रामिण क्षेत्र सम्म पाईने जंगल बाहिरका रुखहरुका बारेमा ज्ञान बढाउनु रहेकोछ । बिशेष उद्देश्यहरु चाहि जंगल बाहिरका रुखहरुका जैविक बिविधता विष्लेशन गर्नु, यी रुखहरुमा भण्डारण भएको कार्बन र यी रुखहरु पाईने स्थानको माटोको जैबिक कार्बन (SOC) को विष्लेशन गर्नु, यी रुखहरुले प्रदान गर्ने ईकोसिस्टम सेवा (सुक्ष्म बासस्थान) को विष्लेशन गर्नु, र यी रुखहरुको (काठ तथा दाउरा) आर्थिक मूल्यांकन गर्नु रहेका छन् ।

यो अनुसन्धान काठमाडौं उपत्यकामा गरिएको थियो । ई. सं. २०१५ मे दखि २०१७ फेब्रुवरी सम्म २०९ स्थानहरुमा तथ्यांक संकलन गरिएको थियो । सोका लागि २० मि. त्रिज्या (radius) को गोलाकार भूखण्डहरु प्रयोग गरिएका थिए । इस भूखण्ड भित्र पर्ने > १.३७ मि. र ≥ ५ से.मी. छातिको उचाईमा ब्यास (DBH) भएका सवै रुख तथा झाडीहरुका रुख स्तरीय बिशेषताहरु अभिलेख गरिएका थिए । साथै हरेक रुखको गुणस्तर बर्ग पनि अभिलेख गरिएको थियो । यदि ती रुखहरुमा एक वा बढी अन्य जीवहरुले बासस्थान वा लहरा बनाई सोमा हुर्केको पाइएमा ती जीवहरुका प्रकार पनि अभिलेख गरिएका थिए । साथै, गूँड, टोड्का तथा दुलो वा चोप भेटिएको भए पनि अमिलेख गरियो । हेरक भूखण्डबाट माटोको जाँचको लागि माटो पनि संकलन गरिएको थियो । त्यस पछि शहर देखि ग्रामिण क्षेत्रसम्म प्रजाति समृद्धि (species richness), समानता सूचकांक (similarity index), प्रजाति बिविधता सूचकांक (species diversity index), समानता (evenness), परिपक्वता सूचकांक (maturity index) प्रजाति समद्धि सूचकांक (species richness index), प्रजाति महत्व मूल्य सूचकांक (IVI), पारिवारीक महत्व मूल्य (FIV), रुखको घनत्व (tree density), फाईटोमास कार्बन स्टक (phytomass carbon stock), SOC, रुख सम्बन्धि सूक्ष्म बासस्थानका (TreMs) साथै रुखको गुणस्तर बर्ग (quality class) काठ तथा दाउरा उत्पादन क्षमता (timber and firewood production potential) र तीनको आर्थिक मूल्यांकन पनि विष्लेशन गरियो ।

यस अनुसन्धानमा जम्मा ६,२१० जंगल बाहिरका रुखहरु अभिलेख गरियो जुन १५० प्रजातिका (रुख = १२१ र झाडी = २९), १११ जेनेरा र ५७ परिवार अन्तर्गत पर्दछन् । ती प्रजाति मध्ये ८० वटा

रैथाने र ७० वटा बाह्य प्रजातिका थिए । अध्ययन क्षेत्रमा औसत प्रजाति संख्या, प्रजाति संमृद्धि, बिविधता सूचकांक, समानता, प्रजाति समृद्धि सुचकांक ६.३२, ५०.२४ प्रति हेक्टर, १.३३, ०.६१ र १.२४ पाईयो । औसत प्रजाति समृद्धि शहरी क्षेत्रमा बढी थियो भने समानता सूचकांक चाहि सबै भन्दा बढी शहरी अर्धशहरी क्षेत्रमा थियो । औसत बिविधता सूचकांक र समानता शहरी क्षेत्रमा बढी थियो भने औसत प्रजाति समृद्धि सुचकांक चाहि ग्रामिण क्षेत्रमा बढी थियो । अध्ययन क्षेत्रको रुखको औसत घनत्व, कार्बन स्टक र SOC क्रमश १३६.३५ प्रति हे, ३२.४० टन प्रति हे र ४२.३२ टन प्रति हे पाईयो । रुखको औसत घनत्व र रैथाने प्रजाति अर्धशहरी क्षेत्रमा, औसत प्रजाति समृद्धि र औसत कार्बन स्टक शहरी क्षेत्रमा र SOC ग्रामिण क्षेत्रमा बढी पाईयो । अध्ययन क्षेत्रमा अभिलेख भएका रुखहरु मध्ये ६४ प्रजातिका १०३८ रुखहरुमा अन्य जीवहरुको बासस्थान रहेको पाईयो । ती बासस्थानहरु जम्मा ४ मूल समूह, ५ समूह र १४ प्रकारका थिए । ती सबै शहरी क्षेत्रमा पनि पाईए । त्यसै गरी ५३ प्रजातिका रुखहरु गोलिया काठ उत्पादन योग्य थिए । ती मध्ये क वर्ग र ख वर्गका गोलिया काठ उत्पादन योग्य प्रजातिहरु शहरी क्षेत्रमा र दाउरा मात्र उत्पादन हुने ग वर्गका रुखहरु चाँहि अर्धशहरी क्षेत्रमा बढी पाईयो । कपूर र सल्ला प्रजातिका रुखहरु क्रमस: गोलिया काठ र दाउरा उत्पादनका हिसाबले बढी बजार भाउ पाईने देखियो ।

यो अनुसन्धानबाट जंगल बाहिरका रुखहरुमा पनि प्रजाति समृद्धि धेरै हुन्छ भन्ने देखियो । अभिलेख गरिएका प्रजातिहरु मध्ये कपूर प्रजातिको रुख कार्बन भण्डारण, सुक्ष्म बासस्थान र व्यापारीक काठ उत्पादनका हिसावले महत्वपूर्ण देखियो । अहिले धेरै जंगल विनास भइरहेको अवस्थामा यस्ता जंगल बाहिरका रुखहरुले जैविक बिविधता र त्यसको संरक्षण, शहरी हरियाली प्रवर्द्धन, वायु स्वक्षता, सूक्ष्म बासस्थानको उपलब्धता र साथै गोलिया काठ तथा दाउरा उत्पादनमा सहयोग पुराउछ । त्यसैले यस्ता जंगल बाहिरका रुखहरुको संरक्षण गर्नुका साथै नयाँ बृक्षारोपण पनि गर्नु पर्दछ । यस बाहेक वन बिज्ञान अन्तर्गत रहेका यी रुखहरु सम्बन्धि थप अनुसन्धानहरु गरिनु पर्दछ ।

मुख्यशब्दहरु: गुणस्तर बर्ग, प्रजाति महत्व मूल्य सूचकांक, प्रजाति बिविधता सूचकांक, रुखको घनत्व, व्यापारीक काठहरु, माटोको अर्गानिक कार्बन, रुख सम्बन्धि सूक्ष्म बासस्थान, क्षेत्र

LIST OF ACRONYMS AND ABBREVIATIONS

A.D.	: Anno Domini: After Jesus Christ Was Born
AGC	: Above Ground Carbon
AGTB	: Above Ground Tree Biomass
a.s.l.	: Above Sea Level
C	: Carbon
CO_2	: Carbon Dioxide
CABI	: Centre for Agriculture and Bioscience International
cm	: Centimeter
cu ft	: Cubic Feet
d	: Depth
D	: Density
DBH	: Diameter at Breast Height
D-D	: Dominance Distribution
DFRS	: Department of Forest Research and Survey
DHM	: Department of Hydrology and Meteorology
DO	: Dominance
ESS	: Ecosystem Services
E	: East
et al.	: et alia (And Others)
F	: Frequency
FAO	: Food and Agriculture Organization
FIV	: Family Importance Value
FRA	: Forest Resources Assessment

FSI	: Forest Survey of India
FY	: Fiscal Year
g	: Gram
GI	: Green Infrastructure
GoN	: Government of Nepal
GPS	: Geographic Position System
H/h	: Height
H'	: Shannon-Weiner Diversity Index
ha	: Hectare
ICIMOD	: International Centre for Integrated Mountain Development
IPCC	: Intergovernmental Panel on Climate Change
IUCN	: International Union for Conservation of Nature
IVI	: Importance Value Index
Kg	: Kilogram
MI	: Maturity Index
m	: Meter
mblm	: Median-Based Linear Models
MEA	: Millennium Ecosystem Assessment
MFSC	: Ministry of Forestry and Soil Conservation
mm	: Millimeter
MP	: Market Price
MV	: Market Value
N	: North
n	: Number

NFI : National Forest Inventory

NFMA : National Forest Monitoring and Assessment

NPR **:** Nepalese Rupee

p : P Value

PAST : Paleontological Statistics Software Package

R^2 : R-Squared (Regression Coefficient)

RD : Relative Density

RDo : Relative Dominance

REDD : Reducing Emissions from Deforestation and Forest Degradation

RF : Relative Frequency

RSS : Rastriya Samachar Samiti

SD/sd : Standard Deviation

SE : Standard Error

SI : Similarity Index

SN : Serial Number

SOC : Soil Organic Carbon

SPSS : Statistical Package for the Social Sciences

t : Ton

TEEB : The Economics of Ecosystems and Biodiversity

TOFs : Trees Outside Forests

TROF : Tree Resources Outside Forests

TreMs : Tree Related Microhabitats

UPF : Urban and Peri-urban Forestry

UN : United Nations

U.S.A.	: United States of America
US	: United States
V/Vol	: Volume
VDC	: Village Development Committee
W/wt	: Weight

LIST OF SYMBOLS

°C	: Degree Celsius
&	: And
%	: Percentage
<	: Less Than
>	: Greater Than
≥	: More Than or Is Equals To
±	: Statistical Margin of Error
+	: Sum
*	: Multiplication
=	: Is Equals To
:	: Is To
ρ	: Rho (Wood Specific Gravity)
$^{-1}$	: Per
$	: Dollar
’	: Inch
”	: Centimeter
√	: Square Root

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CHAPTER 3

CHAPTER 1

1. INTRODUCTION

1.1 Background

Over population mainly due to migration and growth of economic activity has resulted in rapid global urbanization (Seto *et al*., 2005; Wu *et al*., 2015 & Anwar *et al*., 2017). The rate of urbanization will continue to grow at 4% a decade by 2050 (UN, 2015). A high rate of deforestation followed by urbanization as well as suburbanization has resulted the alterd land cover-land use (Vakhlamova *et al*., 2014, Yadav *et al*., 2019). Trees Outside Forests (TOFs) are one of many such alterd land cover-land uses which are of importance for urban greenery and good air quality. Human activities, mainly conversion and habitat degradation are causing global decrease in plant diversity (Newbold *et al*., 2015; Wang *et al*., 2020). Rapid urbanization has changed the composition and diversity of urban vegetation species (Zhang *et al*., 2020) but at the same time, the urbanization gradient may help the recruitment of new co-existing species (Schwoertzig *et al*., 2016a). TOFs, their importance in a number of fields and need of research are described under concerning sub-headings below.

1.1.1 Trees Outside Forests (TOFs)

Food and Agriculture Organization (FAO, 1998) defines trees outside forests (hereafter referred to as TOFs) as "the plants on the land of an area < 0.5 ha and the canopy < 10%". These might be scattered trees found in meadows and pastures; silviculture crops such as fruit trees and coconut; trees in park and gardens, around buildings and in lines along streets, roads, railways, rivers, streams, and canals; trees in shelterbelts of less than 20 m width and 0.5 ha area. TOFs include the trees ranging from a single individual to systematically managed group of trees (Kleinn, 2000). TOFs include both trees as well as shrubs (Foresta *et. al*., 2013). TOFs are found in natural growths such as woodlots, forest fragments, and riparian buffers or cultivated lands such as in farmlands, around lakes, in towns, or small aggregates such as clumps of trees, scattered trees, urban parks, etc. (Bellefontaine *et. al*., 2002). These are found worldwide in many landscapes as natural, cultural, and recently modified landscapes, strata such as urban, suburban, and rural (Baffetta *et al*., 2010; DFRS, 2011). There is some indistinctness in the definition of forests and TOFs. TOFs are also found in different forms as shifting cultivations, rubber plantations, windbreaks and living fences, agroforestry, and urban trees (Langford, 2013).

1.1.2 Assessment of TOFs in the World

TOFs are found in every country and their assessment is the old practice. Realizing their importance, assessments of TOFs had been done in different countries of the world in different time periods. It was started as a part of forest inventory for the first time by Forest Resource Assessment (FRA) in different countries of the world including Costa Rica, France, India, Kenya, Mali, Morocco, Namibia, and Sudan, (Bellefontaine, 2002). Assessments of TOFs have also been done in Uganda (Banana 2002), Central America (Herrera, 2003), Ghana (Dias, 2003), Italy (Baffetta, 2011), Philipines (Dida, 2013), Germany (Maack, 2017), and many others.

In the 1980s, Forest Survey of India (FSI) did the tentative estimation of wood production by TOFs, based on local knowledge or aerial photos **(**FSI, 2000). Later, Kerala Forest Research Institute (KFRI) did a rigorous assessment of trees in non-forested areas, using appropriate sampling methods in the Kerala in 1988-89 (Krishnankutty, 1990). Due to awareness of this resource for rural populations, FSI launched a process to assess TOFs in 1991, starting in the States of Kerala and Haryana. Kumar *et al*. (1994) surveyed the diversity of TOFs in the home gardens of Kerala in peninsular India and reported 127 species of trees and shrubs. A workshop was held in India in 2001 in which the participants discussed on the methodologies for TOFs assessment (Kotwal *et al*., 2001). Pandey (2008) did a review on TOFs resources in 120 districts of India whereas Kumar (2011) did a review on agroforestry research in Kerala where many woody perennial-based land use practices were very common.

In Kenya, the Nakuru-Nyandarua Farm Forestry Project (1990-95) initiated tree plantations for the farmers' benefit and to reduce pressure on existing natural forests. The Ministry of Natural Resources and Environment in Kenya conducted a baseline woody biomass survey in Nakuru and Nyandarua districts in 1991. A survey was done on gazetted forests and farms, which was replicated in 1993 and in 1998 (Pukkhala, 1991; Hoyhtya *et al*., 1998). A detailed woody biomass survey was done in 1991-92 on approximately 10 million ha as part of the Kenya Forestry Master Plan (KFMP) development process that showed an increase in per hectare productivity (Bellefontaine *et al*., 2002).

Similarly, Lengkeek *et al*., (2005) assessed tree density and germplasm source in agroforestry ecosystems in Meru, Mount Kenya where they enumerated 297 species. In Mali where forest land is very scarce, all plant formations including the agroforestry, fields, fallow, and parklands had been inventoried and all wood resources were assessed for planning and management purposes in 1991 (Bellefontaine *et al*., 2002). Species diversity was found greater in fields as compared to fallow lands. Density varied from 8-20 stems/ha in village fields, 9-15 stems/ha in an area under constant cultivation, 15-28 stems/ha in the bushlands and 20-28 stems/ha in the southern Guinean zone. An assessment of carob trees on private and state-owned lands was done in Morocco in 1995 (Bellefontaine *et al*., 2002) where the average density was reported as 16 stems/ha under carob cultivation, 20 trees/ha in state forest, 10 trees/ha in private land and 15 stems/ha in collectively owned land respectively. Inventory of on-farm single trees and woodlots had been done in Namibia (Bellefontaine *et al*., 2002) where average of 20 mature single trees was found on farms while an average density of 9 trees/ha (DBH > 5 cm) with average diameter 11.4 cm; average height 4.8 m was reported. The National Forest Inventory (NFI) in France started the special inventories of hedgerows, line plantings, and scattered trees in 1960 in which a two-stage sampling method with stratification was used (Bellefontaine *et al*., 2002). An inventory done in central Sudan reported 33 species (Bellefontaine *et al*., 2002).

Besides these, Banana *et al*. (2002) developed the provisional methodology for the assessment of TOFs in Uganda. Dias (2003) assessed the spatial distribution of TROF (Tree resources outside forests) in the Ashanti region in Ghana, about the selected physical and socio-economic factors and found that the basal area, number of stems as well as number of stumps correlate significantly with the distance to the villages. Sreetheran *et al*. (2011) did an assessment of street trees in Kuala Lumpur, Malaysia and reported 35 species from 16 families. Dida *et al*. (2013) had done an assessment of TOFs in Selected Makiling sub-watersheds in the Philippines and found the average height of more than 5 m. Soladoye & Oromakinde (2013) enumerated 293 trees of 7 species in the assessement of tree planting activities within the Lagos Island Local Government Area of Nigeria. Poot–Pool *et al*. (2015) observed the home garden agrobiodiversity differentiates along a rural—peri–urban gradient in Campeche, Mexico and enumerated all cultivated species in 12 homegardens. Both total and average species richness of trees and shrubs in rural and semi–rural home gardens were similar while tree density was largest in semi–rural home gardens.

In a study in the semi-arid East Shewa Zone of Oromia, Ethiopia, Endale *et al*. (2016) found 6066 individuals (≥ 2 m) belonging to 77 tree species (70% native and 30% exotic) and 32 families were recorded. The number of tree species per plot varied from treeless condition to 36 tree species with an average of 4.7. The height and DBH ranged from 2 to 25 m and from 1 to 86 cm, respectively. Korichoa *et al*. (2020) did the assessment of the structure, diversity, and composition of woody species of urban forests of Adama city, Central Ethiopia. They recorded a total of 805 individuals with 86 species (68 introduced and 18 native). The Shannon Weiner Diversity Index (H') was 3.61 and the evenness index was 0.80. Bartoli *et al*. (2021) did a comparative analysis of biodiversity of urban street trees in 15 Italian cities and recorded 277 tree species belonging to 48 families and 127 genera.

1.1.3 Assessment of TOFs in Nepal

Study of TOFs is new to Nepal. Based on one development region one district design, Forest Resource Assessment (FRA), for the first time, started the first ground-based TOFs assessment at the regional level in Nepal in 2004/05. The inventory was conducted in Morang, Dhanusha, and Nawalparasi districts. Reports of the assessment in the Morang district indicated the stem density as 15 ha^{-1} (DFRS, 2011). Similarly, Kharal *et al*. (2008) did an assessment of TOFs in the Nawalparasi district and found the stem density as 10 ha^{-1}. Besides these, Acharya (2006) presented a case study of two villages {Chuwa Village Development Committee (VDC) and Shiwalaya VDC} in the western middle hills of Nepal and tried to link the trees on farms with biodiversity conservation. Kharal & Oli (2009) performed an estimation of tree species diversity in rural farmlands in Birendranagar VDC of the Chitwan District where they found a total of 60 tree species. Regmi & Garforth (2010) reported Bakaino, Sissoo, Simal (*Bombax ceiba*), Jamuno (*Syzigium cumini*) and Karma (*Adina cordifolia*) cultivated for timber or wood while Ipil Ipil (*Leucaena leucocephala*), Dabdabe (*Garuga pinnata*), Khanayo (*Ficus cunia*), Ginderi (*Premana latifolia*) and Syakino (*Indigofera atropurpurea*) cultivated for fodder as TOFs in Chitwan District.

Baral *et al*. (2013) assessed all the trees and shrubs as in the rural farming system in Nepal and species richness, tree diversity index and biomass per unit area were analyzed. Das & Heyojoo (2014) did a study to assess TOFs resources in the Panchase area and found that the average tree density in the study area was 195±17 ha^{-1} while average carbon stock was 28.78±7.45 t ha^{-1}. Oli *et al*. (2015) did a study of on-farm trees growing in the Tanahun district where they recorded 92 species and Shannon–Wiener diversity index was 2.46. Besides these, Mandal *et al*. (2015) assessed TOFs to evaluate carbon stocks and plant biodiversity relationship and showed the positive but very weak relationship between carbon stock and species richness. Yadav *et al*. (2017) did a review on importance of TOFs and concluded that TOFs in Nepal's Terai region has significantly increased over the past decade.

1.1.4 TOFs and biodiversity conservation

TOFs are important in terms of biodiversity. Biodiversity is crucial to fulfill different fundamental human needs (Ehrlich & Ehrlich, 1992; Carpenter & Brock., 2006; Diaz *et al*., 2006). TOFs nowadays are important for urban greenery and species conservation (Kharal & Oli, 2009). TOFs in the form of agroforests are very important for species richness and diversity conservation (Kumar, 2011). But, there are considerable decrease in tree cover on agricultural land catagorically reported from West Africa, Tanzania, parts of Ethiopia, Brazil, and Nepal (Zomer *et al*., 2014). TOFs in agroforestry that act as a germplasm source, can be used in inbreeding and genetic erosion (Lengkeek, 2005). Such a method can be used to increase the germplasm diversity of the common tree species with rare species. The existing TOFs should be well conserved and well documented (Acharya, 2006). Development of the mechanisms such as tax exemptions and conservation credits that provide benefits to rural communities as compensation for TOFs in the rural farming system could help in diversity and carbon pool as well as the rural economy (Baral *et al*., 2013).

1.1.5 Legislations related to TOFs biodiversity conservation in Nepal

Though there are many biodiversity conservation legislations for forests and TOFs assessment is mentioned under forests assessment, but nothing has been mentioned about the biodiversity conservation legislations for TOFs (GoN, 2002), (GoN/MFSC, 2014) and (GoN, 2019).

1.1.6 Origin of plant species of TOFs

Plants found in any area could be native or exotic. Both native and exotic trees and shrubs are important for their diversity as well as genetic resources conservation

(Murgueitio *et al*., 2010; Kehlenbeck *et al*., 2011). But due to the urbanization processes, native species are supposed to decline (Kuhn & Klotz, 2005; Vakhlamova *et al*., 2014).

1.1.7 Ecosystem services (ESS)

Ecosystem service is defined as the relative contribution of natural capital to the production of human benefits (Costanza *et al*., 2011). The concept of ecosystem services has become an important model for linking the functioning of ecosystems to human welfare benefits (Fisher *et al*., 2007). An ecosystem includes different 'goods' such as food, medicinal plants, construction materials, tourism, and recreation as well as wild genes for domestic plants and animals (IUCN, 2013). For example, municipal forests primarily provide ecosystem services that are in demand by residents. So, one important piece of data is a valuation of all ecosystem services (Hajek & Lípa, 2015). The structure, function, and services of an ecosystem are not synonymous. But most of the ecosystem structures and processes do provide similar services (Fisher *et al*., 2007). Contrary to the suggestion of the definition by Wunder (2005), some ecosystem services' as public goods (biodiversity, climate regulation, scenic beauty, etc.) or collective goods (water quality in a watershed) do not have a market (Bienabe *et al*., 2017). Ecosystem services can be described, measured, and evaluated according to the relationship between ecosystem services and ecosystem functions (Zhang *et al*., 2015).

Though ESS has been classified, it is not uniform in all cases. Several different typologies and approaches to classify ecosystem services are developed using different criteria. MEA (2005) classified ecosystem services into four broad categories as

- Provisioning services – food, materials, and energy, which are directly used by people;
- Regulating services – those that cover the way ecosystems regulate other environmental media or processes;
- Cultural services – those related to the cultural or spiritual needs of people;
- Supporting services – ecosystem processes and functions that underpin the other three types of services.

TOFs are also important in lessening the pressure on forest ecosystem services (Msuya, 2011). These could help in climate change mitigation and offer a wide range of ecological and socio-economic functions such as carbon sequestration and other environmental services (Plieninger, 2011; Nair, 2011). TOFs as green infrastructure (GI) not only support biodiversity but also benefit ecosystem services (Filazzola *et al*., 2019) and are ecologically significant (Kleinn, 2000; Baffetta *et al*., 2010).

1.1.7.1 Carbon storage

Forests are well known for carbon storage, sinking, combating greenhouse gases, global warming, etc. (Rawat *et al*., 2004) but human activities have damaged them severely forming the forest fragments. The greenhouse gases (GHGs), particularly CO_2 in the atmosphere have been increased due to the industrial revolution (Heyojoo & Nandy, 2015). Inter-governmental Panel on Climate Change (IPCC) estimated that the level of CO_2 in the atmosphere today is 31% higher than that about 250 years back. As TOFs were not included in the national monitoring of tree resources, data about this particular resource was rare (Kleinn *et al*., 2015). But now TOFs are integrated by default into the National Forest Monitoring and Assessment (NFMA) inventory design and NFMA, a program of Food and Agriculture Organization (FAO) now offers the study of TOFs resources. TOFs showing variation in volume and species diversity, also act as varied carbon pools which have the potential of carbon sinks (Kumar & Sen, 2012; Yadav, 2017).

1.1.7.1.1 Phytomass carbon stock

Due to rapid urbanization, anthropogenic CO_2 emissions from cities have significantly increased over the past several decades (Tang *et al*., 2016). Such increasing carbon can be stored within the TOFs in urban areas. Urban development is related to tree species, tree populations, and carbon storage (Collas *et al*., 2017) which are found more frequently at low human settlements. But the study of carbon storage in the urban forest is less common worldwide than in different forest types, woody and non-woody vegetation (Jaman *et al*., 2020). The capacity of carbon storage depends upon the plant species diversity and stand structure (Baul *et al*., 2021). Though there is more focus nowadays on the ecological service of urban forests still more information is required on the variation of carbon in trees and soils in different functional forest types, administrative districts, and urban-rural gradients (Lv *et al*. (2016). Due to large-sized trees and higher tree density out of five carbon pools, carbon stored in the above-ground tree biomass is the largest in forests (IPCC, 2006; Tang *et. al*., 2016). Though the carbon stock density of TOFs in urban green areas is smaller than that of forests, there is the potential for considerably higher storage capacity (Matasov *et al*., 2020).

Home gardens with high agrobiodiversity have a high potential for carbon sequestration, especially in changing environments and targeting to get benefit from reducing emissions from deforestation and forest degradation (REDD+) program in response to climate change (Kumar, 2011; Jaman *et al*., 2016). By the integration of trees on farmland, TOFs in the Terai region of Nepal have significantly increased over the past decade (Regmi & Garforth, 2010). Due to more density of smaller and medium-sized TOFs in rural area, biomass is also less here than in urban area (DFRS, 2007; Kharal *et al*., 2008). Trees and shrubs are important components of the rural farming system in Nepal and act as carbon pools (Baral *et al*., 2013) that may be potential candidate under the Reducing Deforestation and Forest Degradation (REDD+) mechanism (Mandal *et al*., 2014). Though there is a knowledge gap between TOFs resources at the rural level and the policy, TOFs possess good potential for sequestering atmospheric carbon and enhancing plant biodiversity (Yadav *et al*., 2017)**.**

1.1.7.1.2 Soil Organic Carbon (SOC)

The equilibrium of carbon on earth is a function of three reservoirs viz. the oceans, atmosphere, and terrestrial systems which interact and exchange C with each other (Eswaran *et al*., 1993). The soil is important as the sink and source of atmospheric C. So the carbon storage in standing vegetation and in the soil is of great interest (Batjes & Sombroek, 1997). Soil organic carbon (hereafter referred to as SOC) content exhibits variability according to land uses and soil depths (Ghimire *et al*., 2018). The term soil organic matter includes all organic substances in soil, both living and dead (CAB International, 2003). Interestingly, the carbon stored in soils is about triple that in the aboveground biomass and about double that in the atmosphere.

Generally, a change in land use results in a change in SOC. For example, when agricultural land is allowed to revert to natural perennial vegetation, SOC can accumulate more but it decreases in the reverse condition (Dhakal *et al*., 2010; Nyawira *et al*., 2016). As the SOC is usually greater than the vegetation carbon in terrestrial ecosystems, it is very important to understand the dynamics of soil carbon as well as its role in terrestrial ecosystem carbon balance and the global carbon cycle. The loss of SOC by conversion of natural vegetation to cultivated use is well known (Post & Kwon, 2000). So land use and soil management practices can significantly increase the SOC. The relationship between above ground carbon (AGC) and SOC stocks might be masked by other factors such as soil types, precipitation, and land management (Mathew *et al*., 2016).

1.1.7.2 Habitat services

TOFs are important for providing habitat for other organisms, known as tree related microhabitats (TreMs). Some TOFs provide habitat for more than one organisms showing co-occurrence patterns that depend up on tree species, DBH, and the state of the tree (Larrieu & Cabanettes, 2012; Larrieu *et al*., 2014; Paillet *et al*., 2017; Courbaud *et al*., 2021).

The retention of trees as TreMs in forests managed for timber production is essential for fulfilling the objectives of biodiversity conservation (Basile *et al*., 2020; Frey *et al*., 2020). Furthermore, biodiversity conservation should be done by keeping in mind the future of TreM formation too (Courbaud *et al*., 2017; Courbaud *et al*., 2021). Studying and assessment of these by providing guidelines to the concerned can play an important role in the sustainable management of forest ecosystems regarding biodiversity conservation (Khanalizadeh *et al*., 2020; Martin *et al*., 2022).

1.1.8 Economic valuation

Valuation of ecosystem services can be for society and the rest of nature (Farber *et al*., 2002). Economically, there are two value types - Use values and Non-use values (Brander *et al*., 2010). Transect walk, focus group discussion, key informant interview, and expert consultation are some of the indirect methods for a survey of ecosystem services including provisioning, regulating habitat, and cultural and amenity services (Bhandari *et al*., 2018). The valuation of forest ecosystem services can also support the management of urban forests (Hajek & Lipa 2015) but traditional ecological knowledge and appreciation of the multiple uses and services of indigenous trees are gradually eroding (Dhanya *et al*., 2014).

Due to increasing awareness of our fundamental dependence on natural capital and the value of ESS, the quality and quantity of information related to ecosystems and ESS has been growing and is expected to continue (Anderson *et al*., 2017). ESS is often given too little weight in policy decisions because they are not fully captured in commercial markets (Costanza *et al*., 1997). So, the policy and decision-makers at each level need to know the location, amount, and production of each TROF, their contribution to the economy and livelihoods of local communities, and their economic, social, cultural, and environmental value (Boffa, 1999; Zomer *et al*., 2014).

1.1.8.1 Timber and firewood

TOFs serve many ecological and economic functions as forests serve (Kleinn, 2000). TOFs have become an important source of timber globally but still, there are no policies related to the management, harvest, transit, and marketing of timber from TOFs (Ghosh & Sinha, 2018). They play a significant role in addressing the issues of resource sustainability, improving livelihood, food security, reducing the pressure on forest resources, conserving farmland and increase agricultural productivity (Foresta *et al*., 2013). Besides, TOFs also boost the growth of wood-based industries and generating employment by increasing the area under forest (FSI, 2003), especially creating opportunities to rural communities (Asanzi *et al*., 2014).

In some cases, total wood production from TOFs is more than that from the forests (Krishnankutty *et al*., 2008). The rural system usually is rich in natural vegetation (Xiao *et al*., 2017) with more timber production whereas due to rapid urbanization and more TOFs formations have resulted less timber production in the urban area. Tree species selection for afforestation in TOFs will help to minimize the demand-supply gap of timber (Shrivastav *et al*., 2012). Wood includes all timber, industrial wood, firewood, and charcoal (Krishnankutty *et al*., 2008). It is still the most widely used fuel source in developing countries (FAO, 1999). A timber readily harvestable is merchantable timber (Ouattara *et al*., 2014). According to DFRS (2015), a tree can be classified as a quality class A tree (high-quality sound tree) - a live tree that would produce at least one 6 m long saw log; quality class B tree (sound tree) –a live tree which would produce at least one 3 m long saw log; and quality class C tree (cull tree) - a live tree not qualified as class A or class B but would produce firewood only. Bamboo is a part of TOFs that is merchantable for mainly construction work (Bhusal & Bashyal, 2020).

Forest resources, particularly timber, face an uncertain future because of the high deforestation rate, rapid population growth, timber rights allocation system, forest fees, poor law enforcement, increasing demand for timber and energy, and sawmills being export oriented (Oduro *et al*., 2014). Generally, single trees in areas with lower density attain a larger diameter at breast height (DBH) and as a consequence, greater volume (Bembenek *et al*., 2014). Stem volume is an important parameter to estimate the monetary value of timber (Crecente-Campo *et al*., 2009). Categorization of TOFs based on diameter class and timber quality class is necessary for the valuation of the wood (Pompa-García *et al*., 2009; Bembenek *et al*., 2014). The merchantable value of the wood depends on the species (Mejia *et al*., 2015) that gives the idea about the economic importance of that species.

1.1.9 History of tree plantation and preservation in Kathmandu Valley

There were plenty of trees in the Kathmandu Valley in the old era (Sharma, 2021). Religious trees such as pipal and bar were abundant on the roadsides, at crossroads, or near the temples. Many of the planted areas belonged to the government or private guthis. King Jayasthithi Malla (1380 -1395 A. D.) for the first time started tree plantation drive alongside roads and water wells that was continued throughout the Malla and Rana periods. Pipal trees (*Ficus religiosa*) were planted in the rural parts of the Valley at places affording convenient resting spots. During his tenure, Rana Prime Minister Chandra Shamasher (1901-1929 A. D.) expanded and extended many paved paths, and trees were planted on both sides of the way. He imported and planted new species like monkey puzzles (*Araucaria araucana*) from Europe and tried to beautify the Valley's roadsides and palaces. This species along with pines and other varieties were planted along the Keshar Mahal in Lainchaur, Maharajgunj, and other pathways connecting different palaces. After the massive earthquake of 1934 A. D. which destroyed the Valley, Prime Minister Juddha Shamsher Rana (1932-1945 A. D.) adopted new urban planning concepts by encouraging government officials to plant more trees. Some trees planted during that period are still there in various parts of the capital including Maharajgunj, Patan, Balaju, Lainchaur, and Babar Mahal. Later, just a few years back, several old trees along Tundikhel and along the Chabahil-Boudha route were destroyed in the expansion of roads and pedestrian traffic safety.

While implementing the modern urban-environmental planning in the 1960s and 1970s, the Nepal government renovated roads and trails throughout the city (Poudel, 2010). During this process, many fully developed trees of Populus, Eucalyptus, and Monkey Puzzle trees were protected and young ones were planted. In the 1980s, urban environmental planners introduced a three-line green belt and over a hundred thousand fast-growing trees were planted along Ring Road to beautify the Valley. These trees in some places have now again been destroyed to expand the existing ring road. Trees were also planted along Kathmandu to Bhaktapur, a part of the Araniko highway, some of which were illegally felled before authorization of the removal of the remaining trees by the recent government keepingthe safety hazards in mind. Small open patches of road habitats were converted into gardens for the first South Asian Association for Regional Cooperation (SAARC) summit in 1987 (Baral & Kurmi, 2005). After the restoration of democracy in 1990, some individuals and business houses also started sponsoring gardens and traffic islands as a part of their business promotions (Baral & Kurmi, 2005).

Construction of parks such as Ratna Park (Shankhadhar Park), Bhugol Park, Balaju Park, Shankha Park, UN Park, Buddha Park, Tribhuvan Park, etc. at different time intervals also added TOFs in Kathmandu Valley. These helped in beautification, biodiversity, and urban greenery here. Only one botanical garden and zoo of the valley at Godawari and Jawalakhel were built with several native as well as exotic tree species. Baral & Kurmi (2005) reported 85 species (72 Trees and 13 Shrubs) on the roadside plantations. *Caryota* sp. is dominant in round out (Iceland). Mango, a tropical species, and Cedar a subalpine species are also found together. Currently, *Buddleja asiatica*, *Calliandra* sp., *Callistemon citrinus*, *Callistemon lanceolatus*, *Camelia japonica*, *Cassia fistula*, *Cleistocalyx* sp., *Cinnamomum camphora*, *Cupressus torulosa*, *Datura stramonium*, *Deodar cedar*, *Elaeocarpus ganitrus*, *Eucalyptus camaldulensis*, *Ficus bengalensis*, *Ficus benjamina*, *Ficus elastica*, *Ficus religiosa*, *Grevillea robusta*, *Juniperus chinensis*, *Magnolia champaca*, *Michelia kisopa*, *Persia* sp., *Prunus cerasoides*, *Prunus persica*, *Salix babylonica*, *Senna siamea*, *Solandra maxima*, *Syzygium jambos*, etc. are common street trees (Khanal *et al*., 2021; Pandey & Luitel, 2020). Pines are very common for a long time in Kathmandu Valley (Bhuju & Gaire, 2012).

But among the planted trees, some are not very useful (Bohara, 2021). Non-native ornamental, fast-growing deciduous trees such as poplars, and eucalyptus absorb the moisture very fast and lower the groundwater table, and *Jacaranda mimosifolia*, an invasive species. Further, Poplar and eucalyptus the roots of which grow close to the soil surface, can damage the pavements by developing cracks. The most common *Pinus* species used for plantation as *P. roxburghii* (khote salla), *P. wallichiana* (gobre salla), and *P. patula* (patle/patula salla) (exotic), also resulted in the loss of water and other vegetation (The Kathmandu Post, 2019).

1.1.10 Urban-rural gradient

Landscape ecology deals with geography and ecology that is the new concept for studying land use change (Luck *et al*., 2002; Berling-Wolff *et al*., 2004; Ahern *et al*., 2013). The term 'urban-rural' gradient was first coined by McDonnell & Pickett (1990) that in ecology explores the changes in plants from the rural area to the city core (Ranta & Viljanen, 2011). About 65% of plant studies have shown the increasing trend of species richness with moderate urbanization (McKinney, 2008) indicating heterotrophic urban ecosystems (Matasov *et al*., 2020). Plant communities are sensitive to urban expansion and therefore may serve as indicators for human-induced land use change (Vakhlamova *et al*., 2014). They are usually more dependent on the natural environment in rural areas (Xiao *et al*., 2017). With rapid urbanization throughout the world, urban and peri-urban forestry (UPF) has raised the value for its psychosocial, cultural, environmental, and economic benefits to urban dwellers. It is believed that urbanization is one of the major causes of the loss of plant diversity at local and regional levels. The pattern of plant diversity along the urban–rural gradient or urbanization degree is not very clear (Wang *et. al*., 2020). There is a need to know the alteration pattern of plant diversity due to urbanization in urban-rural gradient at the regional scale (Blood et al., 2016).

An urban–rural gradient is used to examine changes in plant species composition related to human-altered habitats. Generally, species richness and Shannon Wiener Diversity Index increase from urban to rural gradient (Vakhlamova *et. al*., 2014). At the same time, the urbanization process increases the number of exotic plant species, decreasing the native as well as rare ones (Kuhn & Klotz, 2006) because urban green spaces compared to rural areas are usually dominated by artificial vegetation (Wang *et al*., 2020). There is always a comparison between exotic and native tree species (Bijalwan, 2015). Moreover, urban trees serve particularly important ecological and environmental functions (Jha *et al*., 2019).

Kathmandu Valley with a rapid urban population growth rate of 3.9 % is one of the fastest-growing urban agglomerations in South Asia (Muzzini & Aparicio, 2013). Mainly due to migration, it is characterized by the rapid population growth in the urban core and the rapid expansion of urban sprawl in the periphery (Chitrakar *et al*., 2014) and (Muzzini & Aparicio, 2013). It has led to the haphazard development of new settlements and neighborhoods (ICIMOD, 2007) resulting in deforestation and forest fragmentation forming TOFs. The fragmentation of lands followed by their high prices has also resulted from a land-pulling mechanism in some areas around Kathmandu. This would result in having no space for planting trees in the cities in the future (Goutam, 2018). So, degradation of the urban environment needs to be arrested, despite the growing pressures. It is this challenge that must be faced, as in a world of dwindling resources, it is the city that can be more resource efficient (Brimblecombe, 2019).

1.2 Rationale of the study

TOFs are little recognized in forest resources assessments, and have recently started receiving attention from the research community and the general public (Kleinn, 2000). Standing trees in urban areas have great significance in terms of biodiversity conservation and urban greenery (Bartoli *et al*., 2021). There is a wide literature of study on urban street trees, focused mainly on species diversity. TOFs also serve as the microhabitats. Study of TOFs in terms of timber production would be important (Oli, 2002) because Nepal's annual import of wood and wooden materials exceeds NPR 6 billion (RSS, 2019). Though an inventory of such TOFs resources is important and is included in forest resources assessment, not many initiatives have been taken so far in Nepal (Oli, 2002). Since FY 2004/05, the Department of Forests Research and Survey (now the Forest Research and Training Center), the Government of Nepal has started the assessment of TOFs at the national level (FAO, 2009). It has finished the assessments in the Terai regions of the country only but not in the Kathmandu Valley. The assessments are limited only to density, diversity and volume by diameter class. Still, the assessments of TOFs in terms of phytosociology, phytomass carbon stock, timber, firewood production, and other Ecosystem services (ESS) along the urban-rural gradient are meager. Kathmandu Valley has all three strata viz. urban, suburban and rural. Thus, this study aims to explore the importance of TOFs (including both trees and shrubs) and assess the phytosociological aspects of TOFs, analyze the phytomass carbon, soil carbon, Tree related microhabitats (TreMs) along with diameter class, quality class, wood production potential and timber and firewood values of TOFs along the urban-rural gradient in Kathmandu valley of central Nepal.

1.3 Hypothesis and research questions

TOFs have diverse plant species which vary in terms of composition, carbon stock and ecosystem services.

Specific objectives, research questions, methods of data collection, and addressed chapters are given in Table 1.

1.4 Objectives

The broad objective of this research is to increase our knowledge in the field of TOFs by understanding biodiversity, carbon stock and ecosystem services provided by TOFs in urban-rural gradient in Kathmandu Valley. The specific objectives of the study are:

1. To assess the diversity of TOFs.
2. To estimate the phytomass carbon and soil organic carbon of TOFs.
3. To assess the ecosystem services (tree related microhabitats) provided by the TOFs.
4. To assess the economic valuation (timber and firewood) of TOFs.

This thesis is divided into six chapters. Chapter 1 covers general introduction to the research topic. Chapters 2-5 comprehensively cover the research findings. Chapter 6 provides overall conclusions and recommendations of the research. The contents of chapters 3, 4 and 5 have already been published in peer reviewed scientific journals and chapter 2 will soon be submitted for publication.

The first objective is specifically analyzed in chapter 2. This chapter assesses the diversity of TOFs.

The second objective is analyzed in chapter 3. This chapter estimates the phytomass carbon and soil organic carbon of TOFs.

The third objective is addressed in chapter 4. This chapter assesses the ecosystem services (tree related microhabitats) provided by the TOFs.

The fourth objective is analyzed in chapter 5. This chapter assesses the economic valuation (timber and firewood) of TOFs.

Table 1: Specific objectives, research questions, and chapters matrix

Specific objectives	Research questions	Data collection method	Chapters
1	Do TOFs contribute in biodiversity?	Recording of all trees and shrubs with ≥ 5 cm DBH in a circular plot of 20 m radius, recording of local names of plant species, plant collection for herbarium preparation.	2
2	Do TOFs help in phytomass carbon stock and contribute to SOC?	Recording of tree level characteristics such as DBH, height of all trees and shrubs with ≥ 5 cm DBH in a circular plot of 20 m radius, collection of soil samples from each sampling plot.	3
3	Are TOFs important for serving tree related microhabitat services?	Recording of all trees and shrubs with ≥ 5 cm DBH serving as TreMs in a circular plot of 20 m radius, recording of number or patches and types of all inhabitants, cavities, nests (birds, ants), beehives and sap runs if present.	4
4	Are TOFs important for timber and firewood production?	Recording of all trees and shrubs with ≥ 5 cm DBH in a circular plot of 20 m radius with their quality classes based on merchantable logs.	5

1.5 Limitations of the study

As the herbs and the woody plants with DBH < 5 cm were not considered in this study, the ecosystem services and their valuations couldn’t be included.

CHAPTER 2

ASSESSMENT OF SPECIES DIVERSITY AND PHYTOSOCIOLOGICAL PARAMETERS OF TREES OUTSIDE FORESTS ALONG URBAN–RURAL GRADIENT IN KATHMANDU VALLEY, NEPAL

2.1 Introduction

Trees Outside Forests (TOFs) comprise tree formations ranging from single discrete tree to systematically managed trees (DFRS, 2011) found in the area < 0.5 ha (FAO, 1998). These are found worldwide in many landscapes including natural, cultural, and recently modified landscapes (Baffetta et. al, 2010) and strata such as urban, suburban, and rural (DFRS, 2011). These are nowadays important for urban greenery and species conservation (Kharal & Oli, 2009). As biodiversity is highly significant to fulfill different fundamental human needs (Ehrlich & Ehrlich, 1992; Carpenter & Brock, 2006; Diaz *et al*., 2006), is ecologically significant (Kleinn, 2000; Baffetta *et al*., 2010). Phytosociology is the mainstream vegetation classification that provides an enormous source of biodiversity information (Dengler *et al*., 2008). The relations between people, forests, and TOFs play a critical role in its conservation (Rudebjer et. al, 2008). TOFs are also important for lessening the pressure on forest ecosystem services (Msuya, 2011). But mainly due to the high rate of deforestation, urbanization as well as suburbanization, plant diversity is decreasing (Vakhlamova *et al*., 2014; Wang *et al*., 2020). TOFs as green infrastructure (GI) not only supports biodiversity but also benefits ecosystem services (Filazzola *et al*., 2019).

Kathmandu Valley is one of the fastest-growing urban agglomerations in South Asia (Muzzini & Aparicio, 2013). Mainly due to migration, its urban core is being expanding rapidly in the periphery (Chitrakar *et al*., 2014). Again, due to land-pulling mechanism in some areas around Kathmandu, there would be no space for planting trees in the cities in the future (Goutam, 2018). So degradation of the urban environment needs to be arrested because it is now the city that can be more resource efficient (Brimblecombe, 2019).

Tree plantation was at its peak during Rana Regime and *Arucaria*, *Eukalyptus*, *Callistimon*, *Grevellia*, etc., was planted on roadsides and inside the palaces (Poudel, 2010). Baral & Kurmi (2005) reported 85 species (72 Trees and 13 Shrubs) on the roadside plantations. Nowadays, different native as well as exotic trees as *Buddleja* *asiatica*, *Calliandra* sp., *Callistemon citrinus*, *Callistemon lanceolatus*, *Camelia japonica*, *Cassia fistula*, *Cleistocalyx* sp., *Cinnamomum camphora*, *Cupressus torulosa*, *Datura stramonium*, *Deodar cedar*, *Elaeocarpus ganitrus*, *Eucalyptus camaldulensis*, *Ficus bengalensis*, *Ficus benjamina*, *Ficus elastica*, *Ficus religiosa*, *Grevillea robusta*, *Juniperus chinensis*, *Magnolia champaca*, *Michelia kisopa*, *Persia* sp., *Prunus cerasoides*, *Prunus persica*, *Salix babylonica*, *Senna siamea*, *Solandra maxima*, *Syzygium jambos*, etc. are commonly found on streets (Khanal *et al*., 2021; Pandey & Luitel, 2020). Pines are also common ones (Bhuju & Gaire, 2012).

Species selection is a must for biodiversity conservation and to increase the ecosystem services of TOFs (Rudebjer *et. al*, 2008). There is a wide literature of study on urban street trees, focused mainly on species diversity (Bartoli *et al*., 2021). Though an inventory of such TOFs resources is important and is included in forest resources assessment, not many initiatives have been taken so far in Nepal (Oli, 2002). Assessments of TOFs had been started in the Terai regions of the country in FY 2004/5 at the Government level in Nepal but not in Kathmandu Valley. This study attempts to explore the importance of TOFs and assess the phytosociological aspects of TOFs along urban–rural gradient in Kathmandu Valley.

2.2 Materials and methods

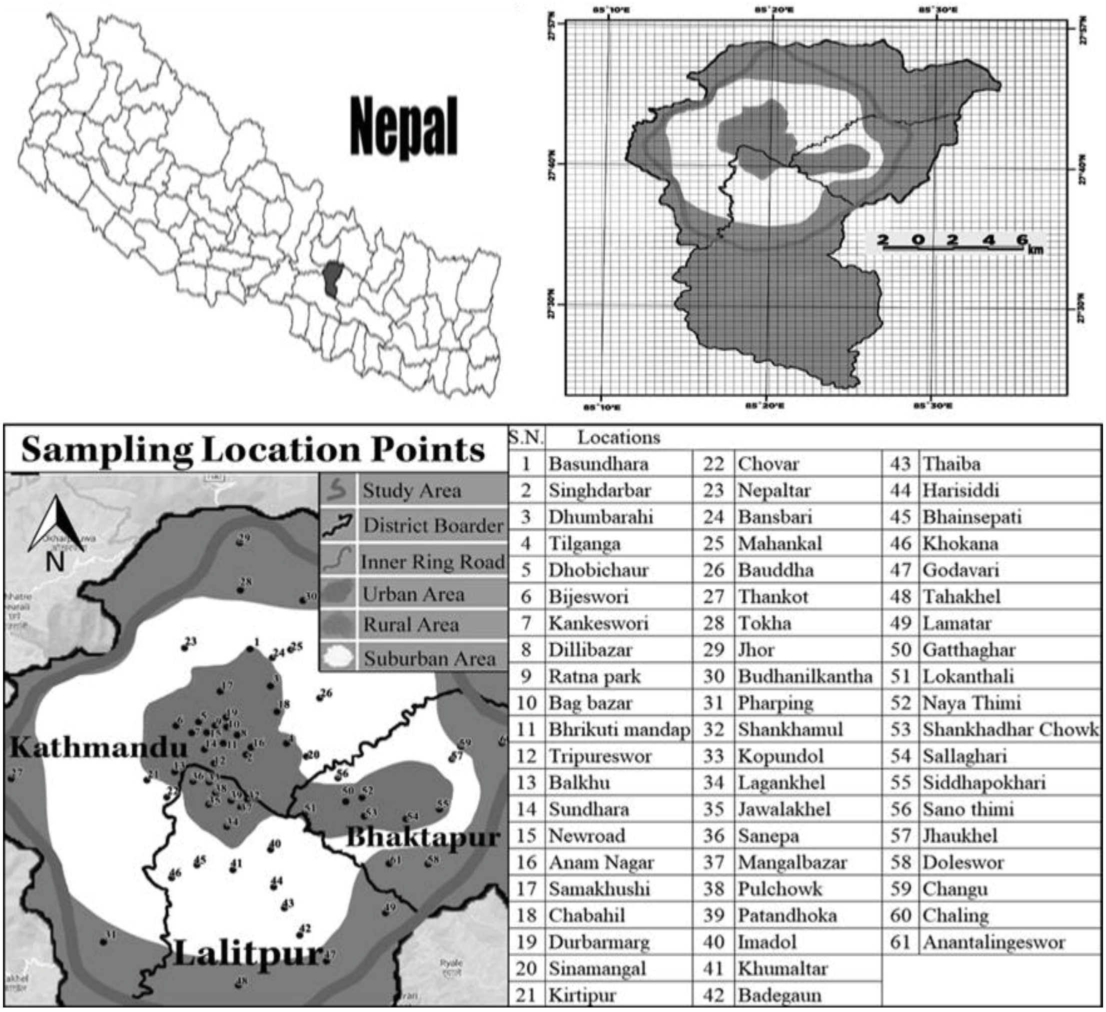
2.2.1 Study area

The study was conducted in Kathmandu Valley in Central Nepal which includes three districts viz. Kathmandu, Lalitpur, and Bhaktapur (Figure 1). It is a bowl-shaped valley, with an area of appx. 66500 ha. It lies between 27°32’13” N to 27°49’10” N latitude and 85°11’31” E to 85°31’38” E longitude. Its elevation ranges between 1,100–2,700 m a.s.l. (Mishra *et al*., 2019) with an average of 1,300 m. It comes under hilly ecological zone. The vegetation is sub-tropical and the climate is monsoon with hot, wet summers and cold, dry winters (ICIMOD, 2007). The average annual minimum and maximum temperatures are 3 °C in January and 29.79 °C in June. The average annual temperature is 19.5 °C. The average annual rainfall is 1509 mm (Department of Hydrology & Meteorology, GoN, 2021) (Figure 2). The fluvial soil of Kathmandu Valley is believed to be highly fertile but nowadays has largely been converted into roads, buildings, commercial complexes, etc.

2.2.2 Methods

2.2.2.1 Site selection and sampling

Two phase sampling method was used (Lister *et al*., 2012). Site selection of TOFs was done by aerial photographs followed by field visits. To survey all TOFs in Kathmandu Valley, grids of 500 m x 500 m were prepared (n = 2800) in the entire study area (Dida, 2016) (Figure 1). A stratified random sampling method was used to identify the locations of TOFs in the grids (DFRS, 2011). From the visual interpretation of Google Earth Image, 1,046 TOFs sites were identified by choosing one TOFs per grid if present under three strata such as urban, suburban, and rural. Stratification was based on population and urban development (GoN, 2014). Stratification of urban strata was up to 500 m outside the existing ring road in Kathmandu and Lalitpur districts. But it was up to 500 m outside the core population center in Bhaktapur district as the ring road does not exist there. The rural stratum was up to 1000 m inwards from the border of the



S.N.	Locations				
1	Basundhara	22	Chovar	43	Thaiba
2	Singhdarbar	23	Nepaltar	44	Harisiddi
3	Dhumbarahi	24	Bansbari	45	Bhainsepati
4	Tilganga	25	Mahankal	46	Khokana
5	Dhobichaur	26	Bauddha	47	Godavari
6	Bijeswori	27	Thankot	48	Tahakhel
7	Kankeswori	28	Tokha	49	Lamatar
8	Dillibazar	29	Jhor	50	Gatthaghar
9	Ratna park	30	Budhanilkantha	51	Lokanthali
10	Bag bazar	31	Pharping	52	Naya Thimi
11	Bhrikuti mandap	32	Shankhamul	53	Shankhadhar Chowk
12	Tripureswor	33	Kopundol	54	Sallaghari
13	Balkhu	34	Lagankhel	55	Siddhapokhari
14	Sundhara	35	Jawalakhel	56	Sano thimi
15	Newroad	36	Sanepa	57	Jhaukhel
16	Anam Nagar	37	Mangalbazar	58	Doleswor
17	Samakhushi	38	Pulchowk	59	Changu
18	Chabahil	39	Patandhoka	60	Chaling
19	Durbarmarg	40	Imadol	61	Anantalingeswor
20	Sinamangal	41	Khumaltar		
21	Kirtipur	42	Badegaun		

Figure 1: Map of the study area. The distribution of the sample points in urban, suburban, and rural strata is shown.

nearest forest of the valley boundary (Katuwal *et al*., 2018). The suburban stratum was in between urban and rural strata. TOFs sites were found more in the urban (440) stratum than in the suburban (366) and rural (240).

From the identified sites, 209 sites (20 %) (Tang *et al*., 2016) [urban (88), suburban (73), and rural (48) strata] were randomly selected by MS Excel for sampling that fell under 61 sampling location points (Figure 1). One sampling plot per site was taken to collect data using a circular sampling plot with a 20 m radius (area = 0.13 ha) (DFRS, 2011) (Figure 3). These sites covered an area of 26.27 ha which was 0.029 % of the total area of Kathmandu Valley.

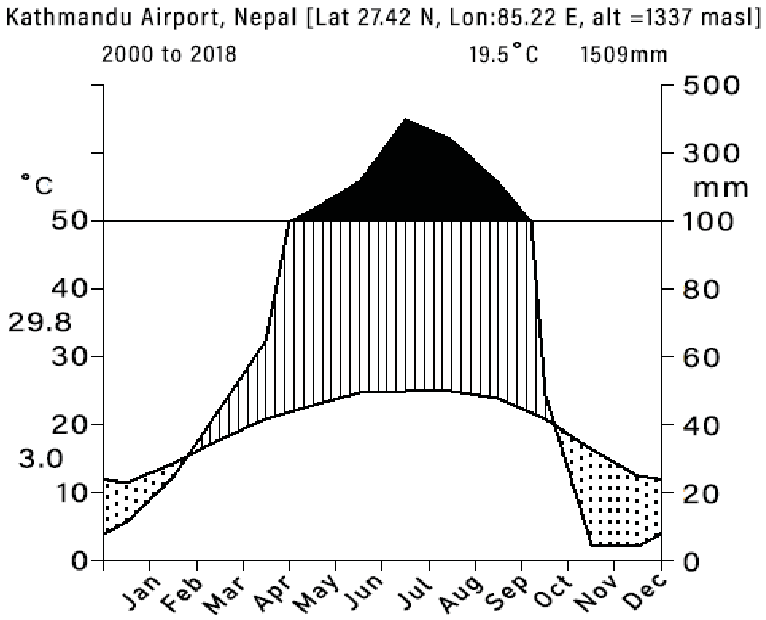


Figure 2: Average annual temperature and average annual rainfall of the study area. (Data between 2000 – 2018; GoN; DHM; airport station, 2021)

Data were collected from May 2015 to February 2017. Geospatial coordinates and altitude of all 209 plots were set in the Geographic Position System (GPS) (Garmin 12 channel GPS) and used as the center point for each plot during data collection. Geospatial coordinates and altitude of the plots were recorded again during the field visits. The study adopted the quantitative and non destructive method. Tree-level characteristics of woody plants with height > 1.3 m and diameter at breast height (DBH) ≥ 5 cm were recorded DBH was measured at 1.3 m above the ground using diameter tape and the tree height was assessed using a Suunto clinometer (PM-5/360 PC).

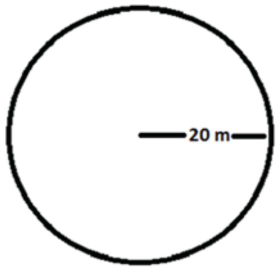


Figure 3: Model of circular sample plot

Plant identification to species level was done based on herbarium specimens prepared following standard procedure (Bridson & Forman, 1998). The vernacular names were recorded by consulting the local people and verified with Sharma (2014). Scientific names were determined after identification by using literature such as Flora of Kathmandu Valley (Malla *et al*., 1986), and after comparison with identified specimens previously deposited at Tribhuvan University Central Herbarium (TUCH), Nepal. Press *et al*. (2000), Shrestha *et al*. (2022), and Plants of the World Online (POWO) (https://powo.science.kew.org/) were followed for plant nomenclature.

2.2.2.2 Data analyses

Species richness is the number of species recorded in a plot (Dorji *et. al*., 2014). Species richness ha^{-1} in a plot and the study area were calculated by dividing the species number by the sampled area. The growth forms of the plants were based on Sharma (2014). He had defined shrub as a woody plant that remains low and produces shoots or trunks from the base, not treelike nor with a single bole while tree as a woody plant that produces one main trunk or bole and a more or less distinct and elevated head.

The similarity index (SI) was determined following Sorensen, 1948.

$$\mathrm{SI} = \frac{2\mathrm{C}}{\mathrm{A} + \mathrm{B}} * 100$$

Where SI = Similarity index, A = the total number of species in stratum A, B = the total number of species in stratum B and C = the total number of species common in both strata.

Frequency, density, dominance, importance value index (IVI), Shannon-Weiner diversity index (H'), and Pielou evenness index (J) of species were calculated following Mandal & Joshi (2014).

$$\text{Frequency} = \frac{\text{Total no: of quadrats in which the species occured}}{\text{Total no: of quadrats studied}} * 100$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{frequency of all species}} * 100$$

$$\text{Density} = \frac{\text{Total no: of individuals of a species}}{\text{Total no: of quadrats studied}}$$

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} * 100$$

$$\text{Abundance} = \frac{\text{Total no: of individuals of a species}}{\text{Total No: of quadrats in which the species occurred}}$$

$$\text{Relative Dominance (\%)} = \frac{\text{Basal area of a species}}{\text{Basal area of all the species}} * 100$$

IVI = Relative frequency + Relative density + Relative dominance

$$\mathrm{H}' = -\sum_{i=1}^{s} (\mathrm{pi})\ (\log\ \mathrm{pi})$$

Where H' = Shannon-Weiner diversity index, p_i = proportion of individuals or abundance of the i^{th} species (total individuals of a species/total individuals of all species)

$$\mathrm{J} = \frac{\mathrm{H}'}{\log \mathrm{s}}$$

Where J = Pielou evenness index, H' = Shannon-Weiner diversity and s = number of species

The maturity index (MI) is an ecological measure of the state of succession (Bongers *et al*., 1997). It is an important indicator of a more developed plant community in a specific area (Shrestha *et al*., 2015). It was calculated across the urban, suburban, and rural strata and the study area according to Pichi – Sermolli (1948).

$$\mathrm{MI} = \frac{\Sigma \mathrm{f}}{\mathrm{n}}$$

Where,

MI = Maturity index of the habitat

f = Frequency of individual species in the habitat

n = Number of species in the habitat.

Menhinick's species richness index (D_{Mn}) shows a relationship between the number of species and the number of individuals. It is applicable in smaller sampling units (Kanieski *et al.*, 2017) and shows Smaller/less sample variation (Karydis & Tsirtsis, 1996).

It was calculated following Menhinick (1964).

$$D_{Mn} = \frac{n}{\sqrt{N}}$$

Where,

D_{Mn} = Menhinick's species richness index

n = Total number of species

N = the Total number of individuals.

The Family Importance Value (FIV) of species was calculated following Mori *et al.*, 1983.

$$\text{FIV} = \text{Relative density} + \text{Relative diversity} + \text{Relative dominance}$$

Where,

$$\text{Relative density} = \frac{\text{Number of trees in a family}}{\text{Total number of trees}} * 100$$

$$\text{Relative diversity} = \frac{\text{Number of species in a family}}{\text{Total number of species}} * 100$$

$$\text{Relative dominance} = \frac{\text{Basal area of family i}}{\text{Total basal area}} * 100$$

2.2.2.3 Statistical analyses

Before the statistical analyses, all data sets were checked for normality using the Shapiro–Wilk test. Even after transformation, data were not found normal, and therefore, non-parametric methods were used. Variations in phytosociological parameters across different strata were tested by the Kruskal-Wallis test followed by Mann-Whitney tests ($p < 0.05$) using statistical software Paleontological Statistics Software Package for Education and Data Analysis (PAST) (Version 4.11). Ordination method was used to show the environment species relation by applying detrended correspondence analysis (DCA) to the sample by species data matrix. The axis length and eigenvalue of DCA 1 were greater than 2.5 and 0.5 respectively and, therefore, a canonical correspondence analysis (CCA) was performed to the species by environment data matrix to investigate the relationship between plant species and environment (altitude and strata). The *vegan* package (2.6 - 4) was used in the RStudio Team (2022) for the analysis.

2.3 Results

2.3.1 Species diversity and phytosociological parameters

Altogether 6210 individuals with 150 plant species [trees (n=121) and shrubs (n=29)] were enumerated from the study area that belonged to 111 genera and 57 families (Appendix I). The species accumulation curve showed that species number increased with the increase of plot number (Figure 4). Out of 150 species, 80 (53.33%) were native and 70 (46.67%) were nonnative or exotic (Appendix I). Details of the native and exotic species across the strata are discussed in chapter 3 too. Species richness was 5.71 ha^{-1} in the study area with an average of 50.24 ha^{-1} (Table 2). The average species richness was higher in the urban stratum than in suburban and rural (Table 5). Similarity indices were 0.66 % (66 species) in urban-suburban, 0.66 % (58 species) in suburban-rural, and 0.63 % (61 species) in urban-rural strata respectively (Table 3, Figure 5). Similarly, 50 species were common in between all three strata. Likewise, family similarity indices were 0.75 % (34 families) between urban-suburban, 0.85 % (36 families) between suburban-rural, and 0.83 % (38 families) between urban-rural strata respectively (Table 4, Figure 6). Similarly, 33 families were common between all three strata.

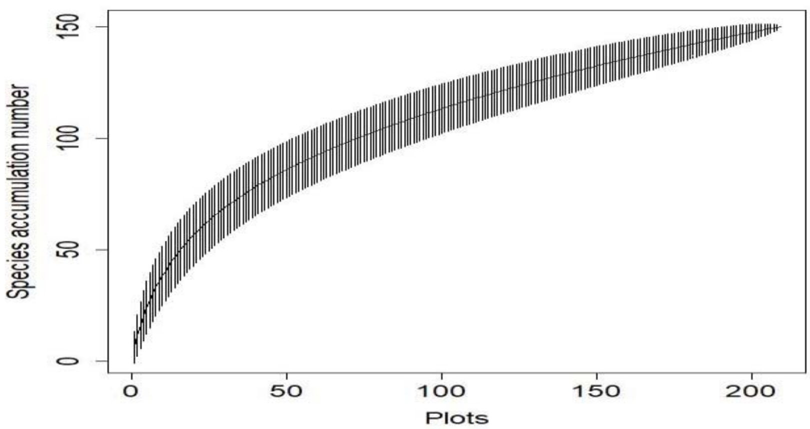


Figure 4: Species accumulation curve in the study area

Table 2: Plot level estimation of phytosociological parameters in the study area (n=209)

	Species number	Species richness (ha^{-1})	Shannon Weiner's diversity index	Evenness	Menhinick's species richness index
	150	5.71	1.68	0.77	1.91
Minimum	1	7.95	0	0	0.08
Maximum	21	167.05	2.8	1.3	2.79
Average	6.32	50.24	1.33	0.61	1.24
SD*	3.6	28.61	0.63	0.29	0.6

* SD=Standard deviation

Table 3: Similarity index (%) of plant species across the strata

Strata	Urban	Suburban
Suburban	0.66	
Rural	0.63	0.66

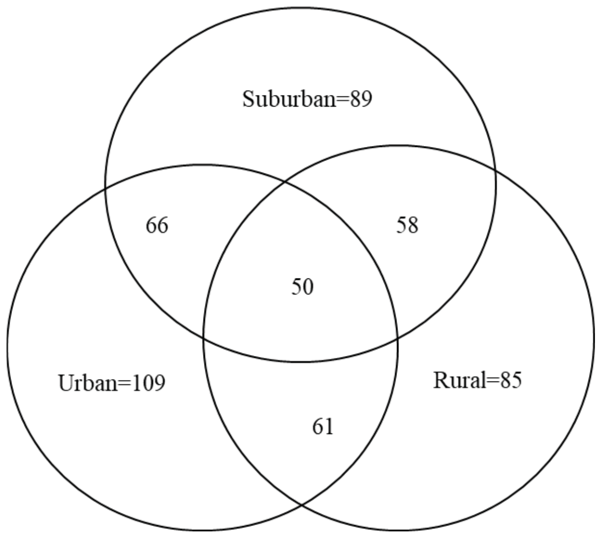


Figure 5: Venn diagram showing common species numbers between urban–suburban, suburban–rural, urban-rural, and urban–suburban–rural strata

Table 4: Similarity index (%) of family across the strata

Strata	Urban	Suburban
Suburban	0.75	
Rural	0.83	0.85

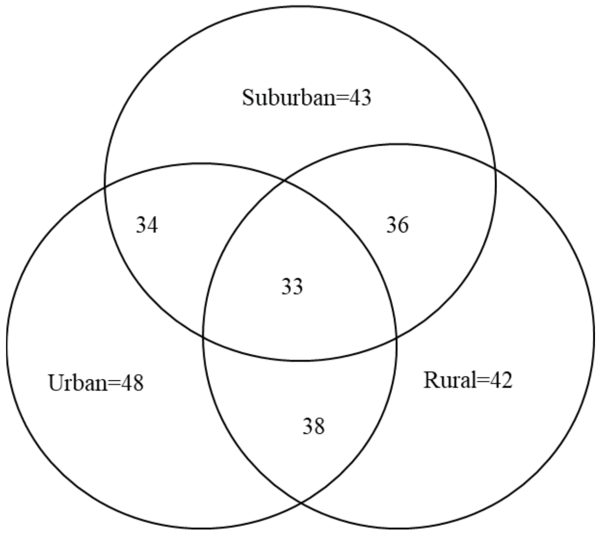


Figure 6: Venn diagram showing common family numbers between urban–suburban, suburban–rural, urban-rural, and urban–suburban–rural strata

Shannon Weiner's diversity index was 1.68 in the study area with an average of 1.33 (Table 2). The average Shannon Weiner's diversity index was significantly higher in the urban stratum than in rural and suburban (Table 5).

Evenness was 0.77 with an average of 0.61 in the study area (Table 2). The average evenness was significantly higher in the urban stratum than in rural and suburban (Table 5).

The maturity index was 4.39 in the study area. It was higher in the rural stratum (6.74) than in the urban (6.39) and suburban (6.38).

Table 5: Plot level estimation of phytosociological parameters in the strata. Different superscript letters across columns indicate statistical significance at $p \leq 0.05$ (Kruskal-Wallis test followed by Mann-Whitney test)

Strata	Total number of plots	Average species richness (ha^{-1})	Average Shannon Weiner's Diversity Index	Average evenness	Average Menhinick's index
Urban	88	55.95 ± 31.67^{a}	1.46 ± 0.63^{a}	0.67 ± 0.29^{a}	1.24 ± 0.61^{a}
Suburban	73	46.31 ± 26.99^{a}	1.23 ± 0.66^{b}	0.56 ± 0.30^{b}	1.23 ± 0.61^{a}
Rural	48	45.74 ± 23.35^{a}	1.24 ± 0.57^{b}	0.57 ± 0.26^{b}	1.28 ± 0.59^{a}

Similarly, Menhinick's species richness index was 1.90 with an average of 1.24 in the study area (Table 2). The average Menhinick's species richness index was higher in the rural stratum than in urban and suburban (Table 5).

Elevation of the studied plots varied from 1246.33 m to 1600 m. It varied from 1246.33 to 1411.53 in urban, from 1262.79 to 1430.12 in suburban and from 1326 to 1600 in rural strata respectively. The canonical correspondence analysis (CCA) was performed to estimate the distribution of plant species in relation to different strata and altitude. High abundance of species such as *Bambusa nepalensis*, *Berberis asiatica*, *Euphorbia pulcherrima*, *Fraxinus floribunda*, *Hibiscus rosa-sinensis*, *Juglans regia*, *Mangifera indica*, *Persea duthiei Schima wallichii* were associated with the rural strata that were characterized by higher elevations of the studied area (Figure 7). High abundance of the species *Populus jacquemontiana*, *Salix tetrasperma* were favored by low elevations which were towards urban stratum of the studied area. Similarly, species like *Pinus roxburghii* were more favored towards the suburban stratum.

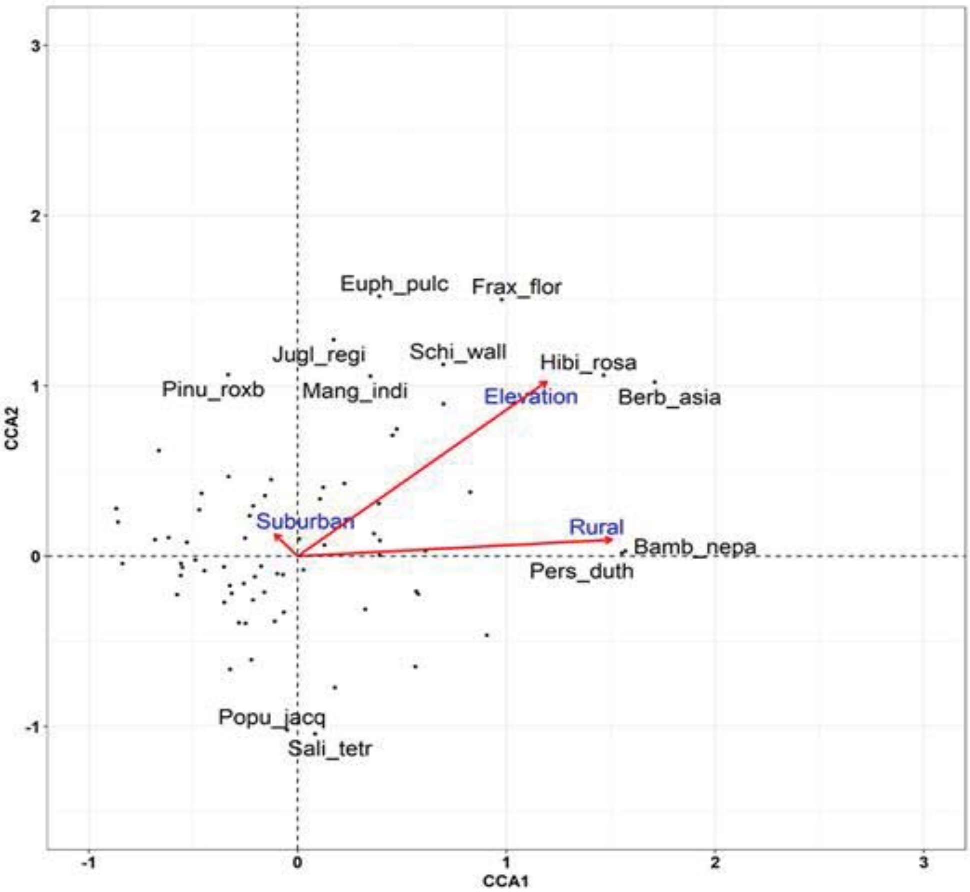


Figure 7: Canonical correspondence analysis (CCA) ordination diagram showing relation between species and environment (elevation and strata) in the studied area.

2.3.2 Species Importance Value Index (IVI)

Grevillea robusta, *Cinnamomum camphora*, and *Thuja orientalis* were the top three most important tree species in the study area (Table 6). They were *C. camphora*, *G. robusta*, and *T. orientalis* in the urban, *Pinus roxburghii*, *G. robusta*, and *T. orientalis* in the suburban, and *Bambusa nepalensis*, *Celtis australis* and *C. camphora* in the rural strata.

The Dominance Distribution (D-D) curve in the study area was relatively longer and sharper than in urban, suburban, and rural strata (Figure 8) indicating the more dominance of *G. robusta* and *C. camphora* in the study area.

Table 6: Highest five and least five plant species with IVI and their relative dominance, relative density, and relative frequency in the study area and the strata

SN	Species	Relative dominance	Relative density	Relative frequency	IVI
		Study area			
1	*Grevillea robusta* A. Cunn. Ex R. Br.	47.76	5.51	4.43	57.71
2	*Cinnamomum camphora* (L.) J. Presl	6.3	7.12	6.1	19.53
3	*Thuja orientalis* L.	1.99	10.27	4.43	16.7
4	*Celtis australis* L.	3.99	3.97	4.58	12.54
5	*Pinus roxburghii* Sarg.	4.34	2.67	4.07	11.08
146	*Pyrus communis* L.	0.0007	0.02	0.07	0.09
147	*Agave cantula* Roxb.	0.0007	0.02	0.07	0.09
148	*Alangium chinense* (Lour.) Harms	0.0007	0.02	0.07	0.09
149	*Cotinus coggygria* (Scop.)	0.0004	0.02	0.07	0.09
150	*Eriobotrya japonica* (Thumb.) Lindl.	0.0003	0.02	0.07	0.09
		Urban stratum			
1	*Cinnamomum camphora* (L.) J. Presl	13.1	11.4	8.32	32.82
2	*Grevillea robusta* A. cunn. Ex R. Br.	11.58	10.22	5.71	27.51
3	*Thuja orientalis* L.	3.13	13.53	5.87	22.53
4	*Ficus religeosa* L.	8.5	3.51	5.06	17.07

5	*Jacaranda mimosifolia* D.Don	7.26	4.97	3.75	15.98
105	*Nerium indicum* Miller	0.001	0.04	0.16	0.2
106	*Duranta erecta* L.	0.001	0.04	0.16	0.2
107	*Cyphomandra betaceae* (Cav.) Sendtn.	0.001	0.04	0.16	0.2
108	*Leucaena leucocephala* (Lam.) De Wit	0.001	0.04	0.16	0.2
109	*Hibiscus brackenridgei* A. Gray	0.001	0.04	0.16	0.2
	Suburban stratum				
1	*Pinus roxburghii* Sarg.	17.55	6.23	4.06	27.83
2	*Grevillea robusta* A. cunn. Ex R. Br.	8.25	4.54	5.73	18.51
3	*Thuja orientalis* L.	5.14	7.18	3.58	15.9
4	*Celtis australis* L.	4.75	4.63	6.21	15.59
5	*Syzygium cumini* (L) Skeels	8.66	4.89	1.67	15.22
85	*Leucaena leucocephala* (Lam.) De Wit	0.004	0.04	0.24	0.29
86	*Euphorbia pulcherrima* Willd. Ex Klotzsch	0.003	0.04	0.24	0.28
87	*Lindera pulcherrima* (Nees) Benth. Ex Hook. F.	0.003	0.04	0.24	0.28
88	*Vitex negundo* L.	0.002	0.04	0.24	0.28
89	*Eriobotrya japonica* (Thumb.) Lindl.	0.002	0.04	0.24	0.28
	Rural stratum				
1	*Bambusa nepalensis* Stapleton	11	17.79	2.18	30.97
2	*Celtis australis* L.	13.93	3.69	5.09	22.71
3	*Cinnamomum camphora* (L.) J. Presl	11.95	3.91	2.91	18.77
4	*Alnus nepalensis* D. Don	3.55	8.19	3.64	15.38
5	*Eucalyptus camaldulensis* Dehn.	11.85	0.96	0.73	13.54
81	*Cotinus coggygria* (Scop.)	0.002	0.07	0.36	0.44
82	*Albizia julibrissin* Durazz.	0.002	0.07	0.36	0.44
83	*Cyphomandra betaceae* (Cav.) Sendtn.	0.002	0.07	0.36	0.44
84	*Michelia champaka* L.	0.001	0.07	0.36	0.44
85	*Syzygium cumini* (L) Skeels	0.001	0.07	0.36	0.44

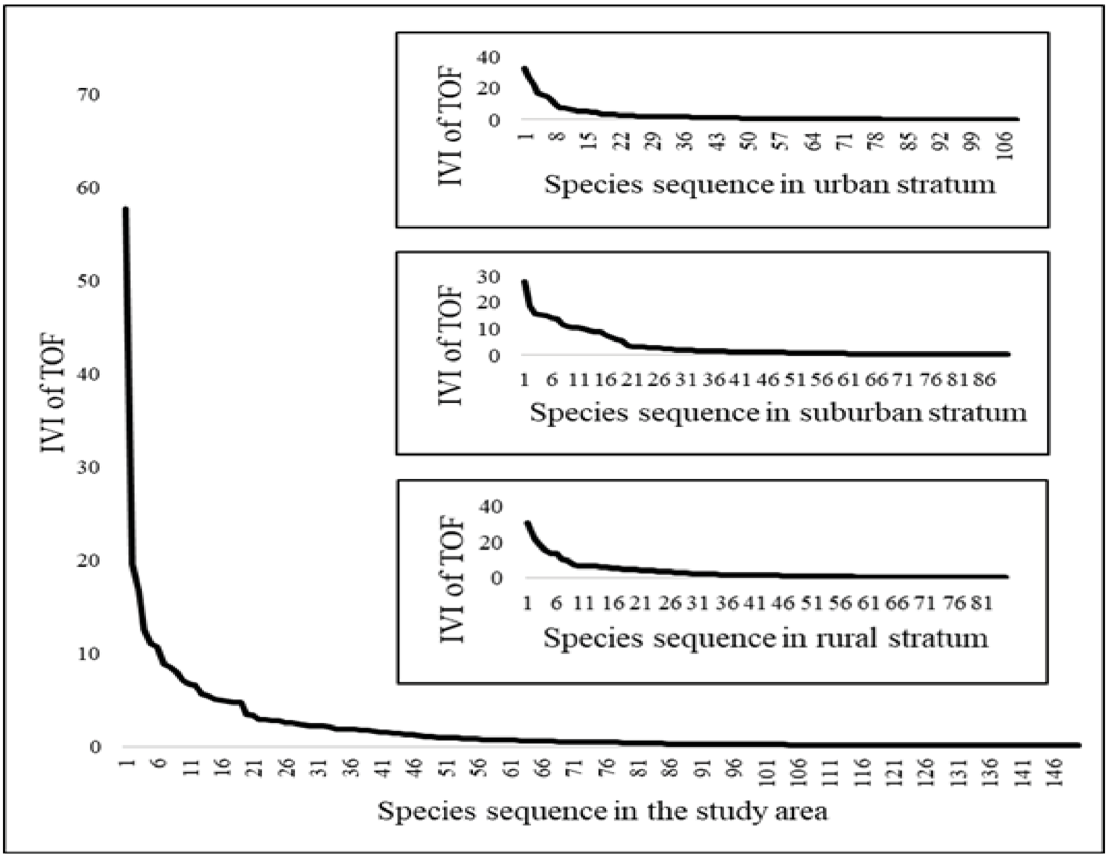


Figure 8: D-D curve of plant species in TOFs in the study area and the strata (inset)

2.3.3 Family Importance Value (FIV)

The dominant species leads to dominance for the respective family (Rahman *et al*., 2020). Proteaceae, Cupressaceae, and Moraceae were the top three most dominant families in the study area (Table 7). They were Lauraceae, Moraceae, and Proteaceae in the urban, Myrtaceae, Cupressaceae, and Moraceae in the suburban, and Gramineae, Myrtaceae, and Cupressaceae in the rural strata respectively.

Table 7: Highest five and least five families with family importance values in the study area and the strata

SN	Family	No. of individuals (ha^{-1})	No. of species in the family	FIV
		Study area		
1	Proteaceae	13	2	51.08
2	Cupressaceae	39	5	22.25
3	Moraceae	22	11	22.17
4	Rosaceae	10	10	20.67

5	Lauraceae	18	6	20.1
53	Sapindaceae	1	1	0.7
54	Fagaceae	1	1	0.7
55	Ginkgoiaceae	1	1	0.69
56	Agavaceae	1	1	0.68
57	Annonaceae	1	1	0.68
		Urban stratum		
1	Lauraceae	28	4	37.97
2	Moraceae	15	8	28.39
3	Proteaceae	23	1	22.71
4	Cupressaceae	33	4	22.12
5	Leguminosae	8	9	15
45	Sapotaceae	1	1	0.96
46	Agavaceae	1	1	0.96
47	Alangiaceae	1	1	0.96
48	Aquifoliaceae	1	1	0.96
49	Verbenaceae	1	1	0.96
		Suburban stratum		
1	Myrtaceae	29	4	40.35
2	Cupressaceae	58	4	34.87
3	Moraceae	15	8	25.32
4	Lauraceae	15	6	20.44
5	Salicaceae	10	2	17.99
39	Fagaceae	1	1	1.25
40	Sapindaceae	1	1	1.22
41	Ginkgoiaceae	1	1	1.2
42	Nyctaginaceae	1	1	1.19

43	Aceraceae	1	1	1.17
			Rural stratum	
1	Gramineae	40	1	29.97
2	Myrtaceae	11	5	24.03
3	Cupressaceae	27	4	19.16
4	Ulmaceae	8	1	18.8
5	Rosaceae	19	6	18.37
38	Ebenaceae	1	1	1.39
39	Araliaceae	1	1	1.34
40	Elaeocarpaceae	1	1	1.29
41	Caricaceae	1	1	1.26
42	Solanaceae	1	1	1.25

The family dominance curve was steep and relatively longer in the study area than in urban, suburban, and rural strata indicating the dominancy of the Proteaceae family (Figure 9).

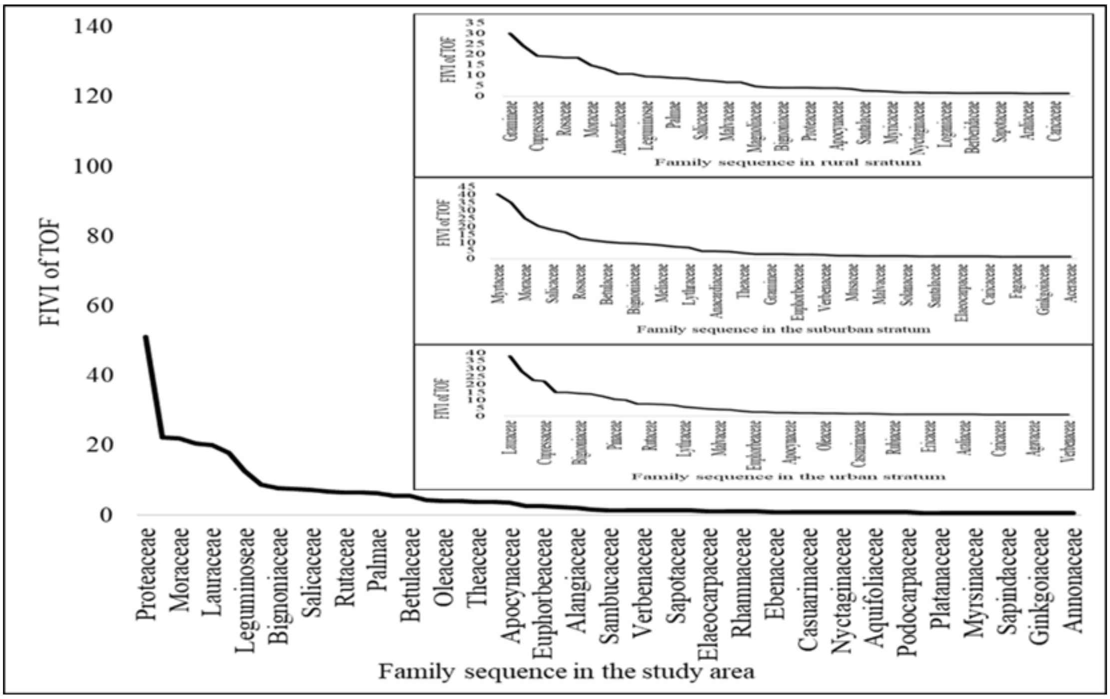


Figure 9: Family dominance curves of the study area and the strata (inset)

2.4 Discussion

Phytosociological parameters vary depending on the land use types. Generally, trees are found less in line plantings, on the roads where homogenous species are generally planted (Lengkeek *et al*., 2005; Lamichhane *et al*., 2010; Soladoye & Oromakinde, 2013; Joshi & Joshi, 2014 and Ramesh *et al*., 2014).

In comparison to the findings in the study area (Table 2), the species number of woody plants was more in Shanghai, China (Wang, 2020). It might be due to the use of different-sized sample plots. Species number was less in Campeche, México (Poot–Pool *et al*., 2015). It might be due to the enumeration of plants in home gardens of rural-periurban areas only. Similarly, Baul *et al*., (2013), Baul *et al*., (2015), Oli *et al*., (2015), and Endale *et al*., (2016) found very low species numbers as individual farms were taken as the plots. But species number was high in large peri-urban home gardens and less in medium and small peri-urban home gardens in Southern Kerala, India (Kunhamu *et al*., 2015). This is due to the enumeration of trees in home gardens only. Due to enumeration from parks only, species number was less in urban and suburban parks in Flanders, Belgium (Cornelis & Hermy, 2004). Due to enumeration from only five major urban roads, Sreetheran *et al*., (2011) found very less species number in Kuala Lumpur, Malaysia. By the enumeration of home gardens, roadside plantations, silvopasture, and agri-silviculture only in rural Kanchanpur, Baral *et al*., (2013) also reported very low species richness. But in contrast, rural home gardens showed very high species numbers (Kumar, 2011) when all the vascular plants were enumerated. Averages species richness in this study showed no significant differences between any of the strata but Schwoertzig *et al*., (2016a) showed significantly more species in Urban sites than in peri-urban and suburban sites. It is due to the tree plantation practice continued by the Rana regime in the urban stratum in our study but the presence of more built surface, heterogeneity, and less vegetation in the urban area of Strasbourg, France.

Due to people's choise for ever-greenness, shade as well as fast growing nature, Muthulingam & Thangavel (2012) found high abundance of *Polyalthia longifolia*, *Azadirachta indica*, *Peltophorum pterocarpum*, *Guazuma ulmifolia*, *Albizia saman* in the urban green spaces of Chennai metropolitan city. Mainly due to plantation, Korichoa *et al*. (2020) found high abundance of *Carica papaya*, *Leucaena* *leucocephala, Persea americana, Grevillea robusta, Podocarpus falcatus, Delonix regia, Citrus medica, Casimiroa edulis* and *Eucalyptus camaldulensis* in urban forests of Adama city, Central Ethiopia. Meanwhile Schwoertzig *et al*. (2016b) reported high abundance of planted and riparian species as *Acer pseudoplatanus*, *Acer platanoides*, *Alnus glutinosa*, *Sambucus nigra* and *Fraxinus excelsior* in the urban sites while high abundance of *Salix alba*, *Acer negundo*, ubiquitous species as *Corylus avellana* and alluvial species as *Prunus padus* in peri-urban sites. Similarly, Kunhamu *et al*. (2015) found the high abundance of planted tree species such as coconut along with *Ailanthus triphysa, Mangifera indica, Artocarpous herterophyllus, Tectona grandis, Artocarpus hirsutus, Thespesia populnea* and *Psidium guajava* in the peri-urban homegardens of Southern Kerala, India. Though not the similar kinf of study as strata, DFRS (2015) reported the strong positive correlation of *Sorbus ursina, Lyonia ovalifolia, Rhododendron arboreum, Rhododendron barbatum,* and *Quercus semecarpifolia* with altitude while a strong negative correlation of *Shorea robusta, Terminalia alata, Lagerstroemia parviflora and Schima wallichii* with the same variable in Middle Mountains Forests of Nepal.

In comparison to our study, Baul *et al*., (2013) and Baul *et al*., (2015), Oli *et al*., (2015), and Endale *et al*., (2016) reported high Shannon Weiner diversity index in farmland as individual farmland was taken as a plot. Home gardens have comparatively high Shannon's diversity index in both suburban (Kunhamu *et al*., 2015) and rural (Kharal & Oli, 2009) strata. But by the enumeration of trees only in home gardens, roadside plantations, silvopasture, and agri-silviculture in rural Kanchanpur, Baral *et al*., (2013) reported a very low Shannon Weiner diversity index. was The higher mean Shannon Weiner’s diversity index in the urban stratum in our study is also supported by the conclusion given by Poot–Pool *et al*., (2015) that diversity does not decline continuously from rural to peri–urban conditions. Land size also matters the species diversity. Baul *et al*., 2015 reported a higher mean species diversity in larger farms than the marginal farms in the northwestern region of Bangladesh. Mean Shannon Weiner's diversity index showed significant differences between urban-suburban and urban-rural strata in our study. Baul *et al*., (2015) also reported significant between different-sized farms. But Cornelis & Hermy (2004) did not find a significant difference between urban and suburban parks.

Tree species in the study area were found to be more evenly distributed than in the Sacred Groves (Shrestha *et al*., 2015) of Kathmandu Valley. Baul *et al*., (2013) and Baul *et al*., (2015) reported high evenness than in our study as individual farms were taken as the plots. According to this study, trees are more evenly distributed in the suburban stratum than in urban and rural strata which might be due to more tree density here. The average evenness

in our study showed a significant difference between urban-suburban and urban-rural strata. Baul *et al*., (2015) showed a significant difference between different-sized farms.

Sacred Groves of Kathmandu Valley was found to be more mature than the TOFs in the study area which is due to the presence of forests in the form of Groves there (Shrestha *et al*., 2015).

Based on disturbances, Giupponi *et al*., (2015) stated that MI was 0 in the areas where rocks/detritus were present, 6.17 in *Calamagrostis varia* grassland, 6.44 in *Festuca cinerea* grassland, 7.49 in *Lupinus polyphyllus–Fraxinus excelsior* community, 7.67 in vegetation dominated by shrubs and broadleaf trees and 8.97 in the montane *Picea abies* forest. Menhinick's species richness index was higher in the rural stratum than in the urban and suburban strata. But it is slightly less in the cold temperate zone (Moktan & Das, 2014) where only the trees were enumerated. Due to more tree density, mean Menhinik’s species richness is higher along the fragmented moist deciduous forests of Northeast India (Majumdar *et al*., 2014). But due to less species number and tree density, mean Menhinik’s species richness is less in western Himalayan moist temperate forests in Kashmir (Shaheen *et al*., 2012).

The Dominance Distribution (D-D) curve in the study area was relatively longer and sharper than in urban, suburban, and rural strata indicating the more dominance of *G. robusta* in the study area. The dominance distribution (D-D) curves are longer in undisturbed forests but sharper and shorter in disturbed forests in both the inner line reserve forest and Barak reserve forest in Assam, India (Borah & Garkoti, 2011). Similarly, Maharjan *et al*. (2016-18) reported steep and long D-D curves for trees than other life forms indicating more dominancy of trees in the Baghmara Buffer Zone Community Forest, Chitwan, Nepal.

The dominant species leads to dominance for the respective family (Rahman *et al*., 2020). The family dominance curve was steep and relatively longer in the study area than in urban, suburban, and rural strata indicating the dominance of the Proteaceae family. It is due to *Grevillea robusta* being the most important tree species in the study area. In contrast to our study, Fabaceae and Rutaceae were the most dominating families in home gardens in Campeche, México (Poot–Pool *et al*., 2015). It is due to the preference of members of these families for plantation by the people based on more ecosystem services. Yumnam *et al*., 2011) gave steep family dominance curves for cultivated and semi-domesticated plants than for wild and crop plants. It might be due to an agriculture-based economy.

2.5 Conclusion

Species richness in TOFs in the study area indicate that though it is less than that in the Middle Mountain Forests of Nepal, it plays a significant role in biodiversity conservation. Trees were more evenly distributed in the suburban stratum. Though the species richness, maturity index, and Menhinick's species richness index were higher in the rural stratum, trees were more diverse in the suburban stratum. *C. camphora* with multiple uses being the dominant plant species in the urban stratum, more benefits should be taken from such plants. Urban greenery is the current issue nowadays, and therefore urban TOFs is very crucial besides the biodiversity and its conservation.

CHAPTER 3[1]

ASSESSMENT OF TREE SPECIES RICHNESS, PHYTOMASS CARBON STOCK AND SOIL ORGANIC CARBON ALONG THE URBAN-RURAL GRADIENT IN TREES OUTSIDE FORESTS OF KATHMANDU VALLEY, NEPAL.

3.1 Introduction

Food and Agriculture Organization (FAO, 1998) defines trees outside forests (TOFs) as "the plants on the land that fulfills the requirements of forest and other wooded lands except that the area is less than 0.5 ha and the canopy is < 10%; scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconut; trees in park and gardens, around buildings and in lines along streets, roads, railways, rivers, streams, and canals; trees in shelterbelts of less than 20 m width and 0.5 ha area". TOFs comprise trees ranging from a single discrete individual tree to systematically managed trees (Kleinn, 2000). These include both trees as well as shrubs (Foresta *et al*., 2013). TOFs may vary from predominantly natural growths to cultivated areas such as clumps of trees, scattered woods, urban parks, etc. (Bellefontaine *et al*., 2002). TOFs offer a win-win land use strategy for climate change mitigation and adaptation through a range of ecological and socio-economic functions such as carbon sequestration and other environmental services (Plieninger, 2011; Nair, 2011). These benefits have made it necessary for governmental bodies and other stakeholders including international organizations to require detailed information on TOFs.

Due to urbanization, more than half of the world's population now lives in urban areas (UN, 2015). Urbanization is believed to be one of the major causes of the loss of plant diversity at local and regional levels. An urban–rural gradient is used to examine changes in plant species composition related to human-altered habitats. But the pattern of plant diversity along the urban–rural gradient or urbanization degree is not very clear

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[1] **Shrestha, B.,** Sharma, B. K., Baniya, C. B., and Yadav, R. K. P. (2023). Assessment of tree species richness and phytomass carbon stock and along the urban-rural gradient in trees outside forests of Kathmandu Valley, Nepal. *Arboricultural Journal*, 1-21. https://doi.org/10.1080/03071375.2023.2241812

(Wang *et. al*., 2020). Generally, the urbanization process increases the number of exotic plant species, decreasing the native as well as rare ones (Kuhn & Klotz, 2006). There is always a comparison between exotic and native tree species (Bijalwan, 2015). Species richness and Shannon Wiener Diversity Index generally increase from urban to rural gradient (Vakhlamova *et al*., 2014). Urban green spaces compared to rural areas are usually dominated by artificial vegetation (Wang *et al*., 2020).

Due to large-sized trees and higher tree density out of five carbon pools, carbon stored in the above-ground tree biomass is the largest in forests (IPCC, 2006; Tang *et al*., 2016). Though the carbon stock density of TOFs in urban green areas is smaller than that of forests, there is the potential for considerably higher storage capacity (Matasov *et al*., 2020). Trees play a significant role in biodiversity conservation, provide natural greenery and contain the phytomass carbon stock. These also help to increase the SOC. Agro-forestry, urban forestry, etc. are some options to overcome the hazards of deforestation. Urban TOFs help to maintain urban greenery (Chaudhry, 2011).

There were many trees in Kathmandu Valley in the past (Sharma, 2021) along roadsides, crossroads, or near temples. Many of the common areas where trees were present belonged to the government or local co-operatives or guthis (Sharma, 2021). The first recorded tree planting was started in the Malla Era and continued up to the Rana Era (Poudel, 2010). During those times, trees were planted on both sides of the path that were expanded and extended. The government adopted urban planning concepts influenced by Western Europe by planting more trees. New species like *Araucaria araucana*, imported from Europe along with pines were planted to beautify Kathmandu Valley urban areas and palaces. With the introduction of modern urban-environmental planning in the 1960s and 1970s, the government renovated roads and trails throughout Kathmandu. In the 1980s, urban environmental planners introduced a three-line green belt. Trees were also planted along either side of other roads (Poudel, 2010), roadside gardens, and traffic islands (Baral & Kurmi, 2005). Many parks were also built during different historical eras. A botanical garden and zoo were also built. Thus, many native as well as exotic tree species were planted, which helped to improve biodiversity, aesthetic value, urban greenery, and carbon storage.

In the current period, migration has rapidly expanded the boundaries of urban Kathmandu (Chitrakar *et al*., 2014); (Muzzini & Aparicio, 2013), leading to the haphazard development of new settlements and neighborhoods (ICIMOD, 2007). This has resulted in deforestation and forest fragmentations forming TOFs. Despite the current awareness of the value of trees, TOFs are less recognized as a forest resource (Kleinn, 2000). Standing trees in urban areas have great significance in terms of biodiversity conservation and urban greenery. These also have potential to improve the environment by storing the atmospheric carbon and to enhance the SOC. Though the assessments of TOFs have been initiated in Nepal (DFRS, 2007), such assessments along the urban-rural gradient are meagre. Thus, this work has been undertaken to assess the patterns of TOFs and to explain the relationship between tree species diversity and phytomass carbon stock as well as SOC along the urban-rural gradient of Kathmandu Valley.

3.2 Materiasls and methods

3.2.1 Study area

Same as in Chapter 2.

3.2.2 Methods

3.2.2.1 Site selection and sampling

Identification of sampling plots and sampling methods up to tree level characteristics were same as in Chapter 2. Methods for plant identification, vernacular names, scientific names were same as in Chapter 2. Following procedure were done for soil sampling.

Soil samples were taken from each plot under urban, suburban, and rural strata. First litter and debris were removed from the soil surface. Then soil samples were taken from five soil pits. The pits were prepared one in every four cardinal directions (north, east, south, and west) 20 m far from the plot center and one at the plot center of the CSP (Baral *et al*., 2013) (Fig 10). Soil samples (200 gr) were taken from 15 cm deep pits for chemical analysis and mixed well then packed in the polythene bag. The samples were labeled properly and air-dried to prevent harmful changes (Zobel et al., 1987). Besides, separate soil samples were collected by driving a steel cylinder/core (height 10 cm and diameter 8 cm) for bulk-density determination (Baral *et al*., 2013).

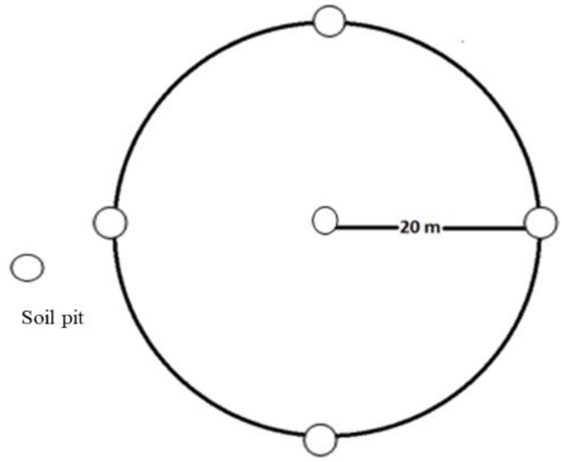

Figure 10: Model of circular sample plot with soil pits

3.2.2.2 Data analysis

Species richness of the study area and across the strata were estimated for the area sampled at the study area and each stratum. Average species richness was calculated as the total number of species recorded per plot (Dorji *et al*., 2014). Origin (Native/Exotic) of the species was done based on Kew Science, Plants of the World Online. Tree density was calculated by dividing the number of plants by the respective area. The Importance Value Index (IVI) of species was calculated by following Mandal & Joshi (2014). Above-ground tree biomass was calculated by using the following allometric equation given by Petersson *et al.* (2012):

$$AGTB = 0.0509\, \rho\, D^2\, H$$

Where, AGTB = aboveground tree biomass (kg), ρ= wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), and H = tree height (m).

Wood-specific gravity was used from the equation developed by Sharma & Pukkala (1990) and other published literature (Zanne *et al*., 2009; Sharma *et al*., 2014). Wood-specific gravity values were not available for all species in the study area. For tree species with unknown wood-specific gravity, the arithmetic mean of all known tree species in the study area was substituted (Brown *et al*., 1989) (Appendix II). Similarly, for shrub species with unknown wood-specific gravity, the arithmetic mean of all known shrub species in the study area was used (Appendix II). The biomass stock density (in kg m^{-2}) was calculated by summing up individual weights of a sampling area and dividing it by the total sampled area. The value was converted to ton ha^{-1} after multiplying it by 10 (Subedi *et al*., 2010). AGTB was then converted into phytomass carbon stock density by multiplying with 0.47 (IPCC, 2006). The root-to-shoot ratio value of 1:5 (20% of AGTB) was used to find below-ground biomass (MacDicken, 1997). The total carbon stock density of trees of particular vegetation was calculated by summing up above-ground and below-ground tree carbon stock densities.

Soil bulk density was determined using the core sampling method (Blake and Hartge, 1986). Oven-dry (at 105 °C) soil samples were used for moisture correction. The bulk density of soil was calculated by the following formula-

$$BD = W/V$$

Where,

BD = Bulk density (g/cm^3)

W = Oven Dry Weight of soil (g)

V = Volume of soil (cm^3)

The carbon concentration (%) of the collected soil samples was analyzed in the Soil Analytical Laboratory of the Department of Forestry Research and Survey (DFRS), Babarmahal. A standard titration method (Walkley-Black, 1934) was applied to measure the carbon concentration. The soil organic carbon was calculated as (Pearson et. al 2007):

$$SOC = Rho*d*\%C$$

Where,

SOC = soil organic carbon stock per unit area (t ha^{-1})

Rho = soil bulk density (g cm^{-3})

d = the total depth at which the sample was taken (cm)

% C = carbon concentration (%)

3.2.2.3 Statistical analysis

Before the statistical analyses, all data sets were checked for normality using the Shapiro–Wilk test ($p > 0.05$). Even after transformation, the data was not found to be normal, and therefore, non-parametric methods were used. Variations in species richness, tree-related parameters, and phytomass carbon across different strata were tested by the Kruskal-Wallis test followed by Mann-Whitney tests ($p < 0.05$) using statistical software Paleontological Statistics Software Package for Education and Data Analysis (PAST) (Version 4.11). To understand the relationship between species richness and phytomass carbon over the entire study area, and considering the non-normal nature of data, a non-parametric alternative of linear regression was used. Nonparametric regression is used to describe the trend between a response variable and one or more predictors. This is different from classical regression models in that it does not rely on strong assumptions regarding the shape of the relationship between the variables (Hazelton, 2015; Cizek & Sadıkoglu, 2020). So to examine the relationship between phytomass carbon and species richness the Kendall–Theil Sen Siegel nonparametric linear regression analysis is executed using the *mblm* package in Rstudio (Mangiafico, 2016; Rstudio Team, 2022). Kendall–Theil Sen Siegel nonparametric linear regression analysis was done to examine relationship between SOC and phytomass carbon stock too.

3.3 Results

3.3.1 Species richness and tree density

Altogether 150 species of TOFs belonging to 111 genera and 57 families were enumerated from the entire study area (26.27 ha). The species number recorded varied from 1 to 21 with an average of 6.32 ± 3.60 (Table 8). Species richness was 5.71 ha^{-1}. Tree density varied from 15.91 ha^{-1} to 1217.05 ha^{-1} with an average of 236.35 ± 173.12 ha^{-1}. Out of 150 species, 80 (53.33%) were native and 70 (46.67%) were nonnative or exotic (Appendix I). A larger number of species was recorded in the urban stratum (109) than in the suburban (89) and rural strata (85) (Table 9). But species richness was found higher in the rural stratum (14.09 ha^{-1}) than in the urban (9.85 ha^{-1}) and suburban (9.70 ha^{-1}) strata. The average species number was found higher in the urban stratum (7.03±3.98) than in the suburban (5.82±3.39) and rural (5.75±2.94) strata. But average

Table 8: Minimum, maximum, and average values (±SD) of species number and tree density in the study area.

	Species number recorded	Tree density (ha^{-1})
Minimum	1	15.91
Maximum	21	1217.05
Average	6.32±3.60	236.35±173.12

species richness was found higher in the urban stratum (55.95±31.67 ha^{-1}) than in the suburban (46.31±26.99 ha^{-1}) and rural (45.74±23.35 ha^{-1}) strata. Native species were found higher in number in both urban and suburban strata whereas exotic species were found higher in rural (Figure 11). This data shows that urbanization does not hamper native species. Based on native species, the suburban stratum was richer than the urban and rural strata. Similarly, average tree density was found higher in the suburban stratum (248.44±198.56 ha^{-1}) than in the urban (232.58±155.08 ha^{-1}) and rural (224.88±165.31 ha^{-1}) strata. Species number, species richness, and tree density did not show significant differences across strata as compared with their means (Kruskal-Wallis test, $p < 0.05$) (Table 9).

Table 9: Number of plots, species number recorded with range, species richness (ha^{-1}), and average values (±SD) in TOFs in the strata. Different superscript letters across columns indicate statistical significance at $p \leq 0.05$ (Kruskal-Wallis test).

Strata	Total plots	Species numbers recorded with a range	Species richness (ha^{-1})	Average species number	Average Species richness (ha^{-1})	Average tree density (ha^{-1})
Urban	88	109 (1-21)	9.85	7.03±3.98 ^{a}	55.95±31.67 ^{a}	232.58±155.08 ^{a}
Suburban	73	89 (1-16)	9.70	5.82±3.39 ^{a}	46.31±26.99 ^{a}	248.44±198.56 ^{a}
Rural	48	85 (2-15)	14.09	5.75±2.94 ^{a}	45.74±23.35 ^{a}	224.88±165.31 ^{a}

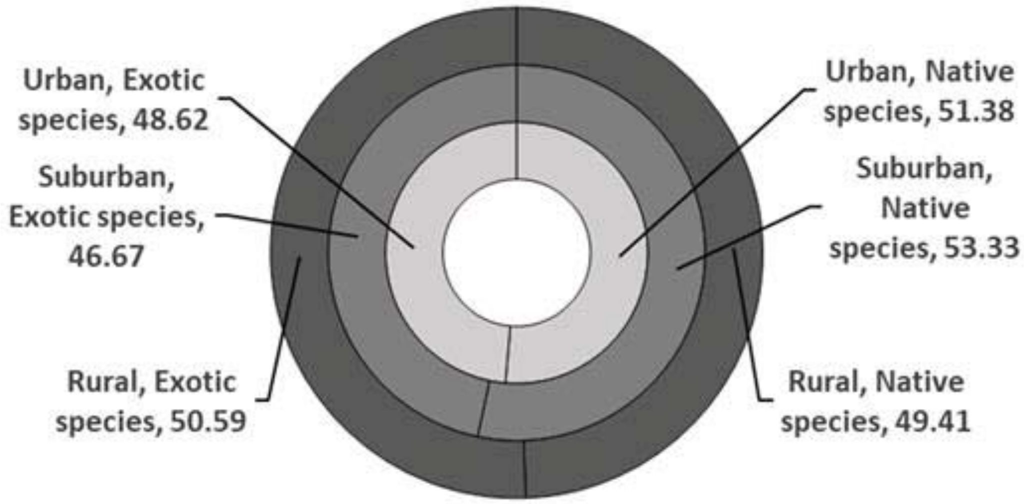

Figure 11: Doughnut chart showing percentages of native and exotic plant species across the strata

3.3.2 Importance Value Index (IVI)

Table 10 presents the IVI of tree species present in the study area. The ten tree species with the highest IVI values include *Grevillea robusta* (IVI = 57.71), *Cinnamomum camphora* (IVI = 19.53), *Thuja orientalis* (IVI = 16.70), *Celtis australis* (IVI = 12.54), *Pinus roxburghii* (IVI = 11.08), *Ficus religeosa* (IVI = 10.72), *Jacaranda mimosifolia* (IVI = 8.85), *Juniperus indica* (IVI = 8.57), *Populus jacquemontiana* (IVI = 7.94) and *Callistemon citrinus* (IVI = 6.99). *C. camphora* (IVI=32.82), *G. robusta* (IVI=27.51), and *T. orientalis* (IVI=22.53) were the most important tree species in the urban stratum. *P. roxburghii* (IVI=27.83), *G. robusta* (IVI=18.51), and *T. orientalis* (IVI=15.90) were the most important tree species in the suburban stratum. Similarly, *Bambusa nepalensis* (IVI=30.97), *C. australis* (IVI=22.71), and *C. camphora* (IVI=18.77) were the most important tree species in the rural stratum.

Table 10: TOFs species with their Relative dominance, Relative density, Relative frequency, and importance value index (IVI) in the study area. Number 1 to 5- top five dominating species and number 146 to 150- least five dominating species.

SN	TOFs species	Relative dominance	Relative density	Relative frequency	IVI
1	*Grevillea robusta* A. cunn. Ex R. Br.	47.76	5.51	4.43	57.71
2	*Cinnamomum camphora* (L.) J. Presl	6.30	7.12	6.10	19.53
3	*Thuja orientalis* L.	1.99	10.27	4.43	16.70
4	*Celtis australis* L.	3.99	3.97	4.58	12.54
5	*Pinus roxburghii* Sarg.	4.34	2.67	4.07	11.08
146	*Ginkgo biloba* L.	0.004	0.02	0.07	0.09
147	*Juniperus communis* L.	0.001	0.02	0.07	0.09
148	*Miliusa velutina* (Dunal) Hook.f. & Thombs	0.002	0.02	0.07	0.09
149	*Pyrus communis* L.	0.001	0.02	0.07	0.09
150	*Ricinus communis* L.	0.001	0.02	0.07	0.09
	Total	100	100	100	300

3.3.3 Tree height, DBH, and phytomass carbon stock

In this study, the average height of trees varied from 1.63 to 20.37 m with an average of 7.28±0.19 m whereas average DBH varied from 6 to 100.55 cm with an average of 24.68±0.95 cm (Table 11). Trees were not found very tall and very wide in some plots. The height of the tallest tree varied from 2 to 31.50 m with an average of 12.60±0.36 m while the DBH of the widest tree varied from 7.20 to 203 cm with an average of 66.15±2.43 cm. Average tree height and average DBH were found higher in urban (8.15±0.34 m and 25.55±2.70 cm) than in suburban (7.01±0.28 m and 24.07±1.43 cm) and rural (6.09±0.29 m and 24.01±2.70 cm) strata (Table 12). The average height of the tallest tree was higher in the urban (14.82±0.69 m) stratum than in the suburban (11.35±0.42 m) and rural (10.43±0.41 m) strata whereas the average DBH of the widest tree was higher in urban (72.46±3.99 cm) than in rural (65.03±5.85 cm) and suburban (59.28±3.13 cm) strata.

Table 11: Minimum, maximum, and average values (±SE) of average height, average DBH, tallest tree, widest tree, and phytomass carbon stock in the study area.

	Average height (m)	**Average DBH (cm)**	**Tallest tree (m)**	**Widest tree (cm)**	**Phytomass carbon stock (t ha^{-1})**	**SOC (t ha^{-1})**
Minimum	1.63	6	2	7.20	0.23	2.50
Maximum	20.37	100.55	31.50	203	299.56	116.40
Average	7.28±0.19	24.68±0.95	12.60±0.36	66.15±2.43	32.40±2.66	42.32±1.57

The average height of trees and the average height of the tallest trees showed significant differences between urban-suburban and urban-rural strata but not between suburban-rural strata as compared with their means (Kruskal-Wallis test, $p \leq 0.05$). The average DBH of trees showed no significant differences across the strata. Similarly, the average DBH of the widest tree showed significant differences between suburban-rural strata but no significant differences between urban-suburban and urban-rural strata.

Table 12: Average values of tree height, tree DBH, tree height of the tallest tree, tree DBH of the widest tree, and phytomass C stock with (±SE) in three strata of the study area. Different superscript letters across columns indicate statistical significance at $p \leq 0.05$ (Kruskal-Wallis test)

Strata	Average height (m)	Average DBH (cm)	Average height of the tallest tree (m)	Average DBH of the widest tree (cm)	Average phytomass C stock (t ha^{-1})
Urban	8.15±0.34 ^{a}	25.55±2.70 ^{a}	14.82±0.69 ^{a}	72.46±3.99 ^{ab}	39.41±4.38 ^{a}
Suburban	7.01±0.28 ^{b}	24.07±1.43^{a}	11.35±0.42 ^{b}	59.28±3.13 ^{a}	26.06±2.94 ^{a}
Rural	6.09±0.29 ^{b}	24.01±2.70 ^{a}	10.43±0.41 ^{b}	65.03±5.85 ^{b}	29.19±6.91 ^{b}

Phytomass carbon stock varied from 0.23 t ha^{-1} to 299.56 t ha^{-1} with an average of 32.40±2.66 t ha^{-1} (Table 11) in the study area. Trees with the highest carbon stock were *C. camphora* (810.97 t ha^{-1}), *G. robusta* (680.78 t ha^{-1}), and *P. roxburghii* (593.63 t ha^{-1}) (Table 3.6 13). The average phytomass carbon stock was found higher in the urban stratum (39.41±4.38 t ha^{-1}) (Table 12) where *G. robusta* (454.52 t ha^{-1}), *C. camphora* (451.49 t ha^{-1}), and *F. religeosa* (338.02 t ha^{-1}) were the highest carbon-storing tree species. The average phytomass carbon stock in the suburban stratum was 26.06±2.94 t ha^{-1} where *P. roxburghii* (243 t ha^{-1}), *Syzygium cumini* (234.39 t ha^{-1}) and *Eucalyptus camaldulensis* (187.74 t ha^{-1}) were the highest carbon storing tree species. Similarly, the average phytomass carbon stock in the rural stratum was 29.19±6.91 t ha^{-1} where

Table 13: Tree species, number of individuals, and phytomass carbon stored in them in the study area. Number 1 to 5- top higher and number 146 to 150- least five ones.

SN	Tree species	Number of individual trees	Phytomass carbon stock (t ha^{-1})
1	*Cinnamomum camphora* (L.) J. Presl	427	810.97
2	*Grevillea robusta* A. cunn. Ex R. Br.	373	680.78
3	*Pinus roxburghii* Sarg.	240	593.63
4	*Ficus religiosa* L.	159	541.96
5	*Populus jacquemontiana* Dode.	126	440.80
146	*Cyphomandra betaceae* (Cav.) Sendt	2	0.02
147	*Jasminum mesnyi* Hance	3	0.02
148	*Ricinus communis* L.	1	0.02
149	*Vitex negundo* L.	1	0.012
150	*Eriobotrya japonica* (Thumb.) Lindl.	1	0.008
	Total	6210	6771.52

C. camphora (267.33 t ha^{-1}), *E. camaldulensis* (179.90 t ha^{-1}) and *Schima wallichii* (136.83 t ha^{-1}) were the highest carbon-storing trees species. The average phytomass carbon stock showed significant differences between urban-rural and suburban-rural strata but not between urban-suburban strata as compared with their means (Kruskal-Wallis test, $p \leq 0.05$) (Table 12).

3.3.4 Relation between species richness and phytomass carbon stock

The Kendall–Theil Sen Siegel nonparametric linear regression analysis to examine the relationship between phytomass carbon stock (t ha^{-1}) and species richness showed a significant positive linear relationship (Figure 12). The analysis does not return the R^2 values. However, the intercept was 14.35 ($p < 0.001$) and the slope for species richness was 0.34 ($p < 0.01$).

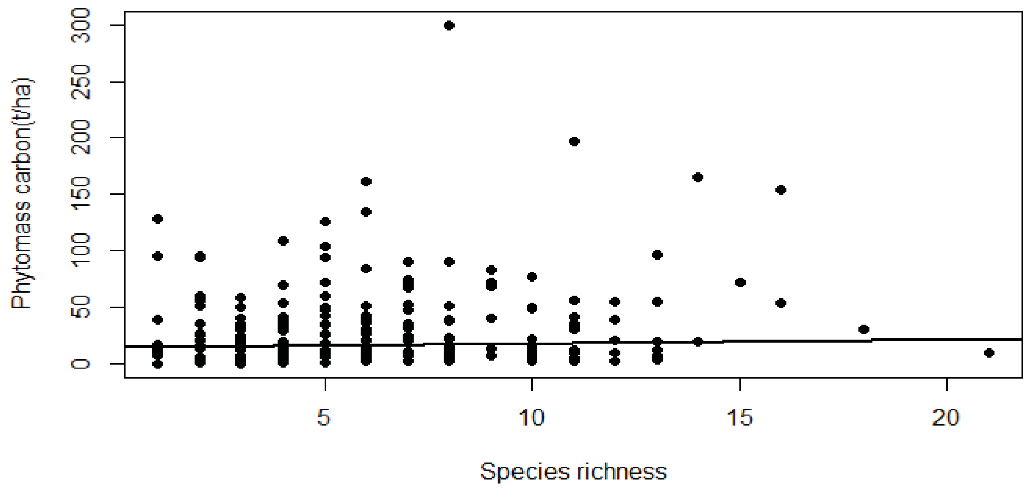

Figure 12: Relationship between species richness and phytomass carbon stock in the study area.

3.3.5 Soil Organic Carbon (SOC)

The SOC varied from 2.50 to 116.40 t ha^{-1} in the study area with an average of 42.32± 1.57 t ha^{-1} (Table 11). It didn't show significant differences across strata as compared w ith their means (Kruskal-Wallis test, $p < 0.05$) (Table 14).

Table 14: Average SOC (±SE) in TOFs in the strata. Different superscript letters across column indicate statistical significance at $p \leq 0.05$ (Kruskal-Wallis test).

Strata	Average SOC (t ha^{-1})
Urban	39.96±2.51 ^{a}
Suburban	43.54±2.63 ^{a}
Rural	44.78±3.05 ^{a}

3.3.6 Relation between phytomass carbon stock and SOC

The Kendall–Theil Sen Siegel nonparametric linear regression analysis to examine relationship between soil organic carbon (SOC t ha^{-1}) and phytomass carbon (t ha^{-1}) showed a significant positive linear relationship (Figure 13). The analysis does not return the R^2 values. However, the intercept was 40.39 ($p < 0.001$) and slope for phytomass carbon was 0.13 ($p < 0.001$).

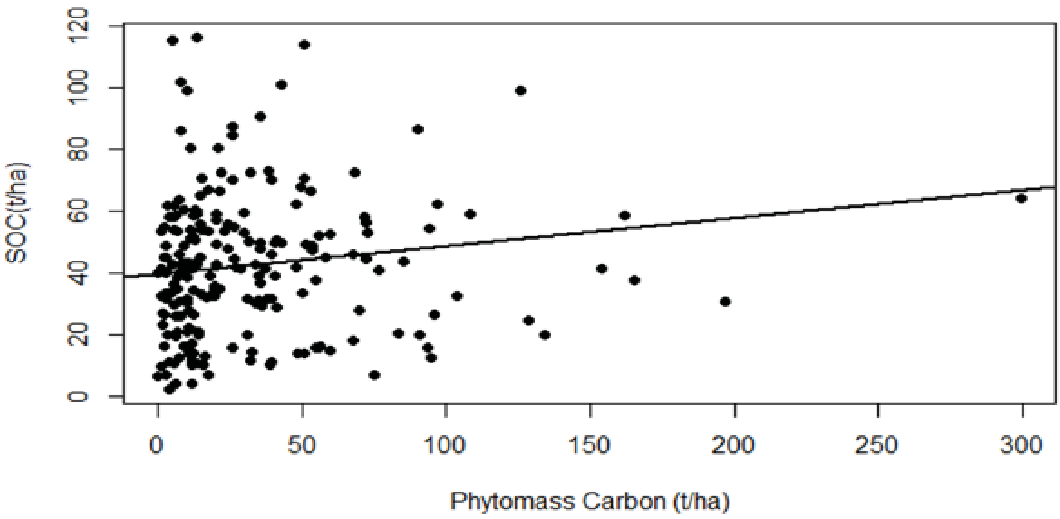

Figure 13: Linear regression between phytomass C-stock and SOC in the study area. The fitted line is based on linear regression.

3.4 Discussion

TOFs species number in the study area is lower than that of the mid-hills mountain forests (1147) (DFRS, 2015) but comparatively higher than that of the Bajrabarahi Sacred Grove (18) and Pashupati Sacred Grove (17) in the same study area (Shrestha *et al*., 2015). Variation in the number of species per parcel (Schmitt-Harsh *et al*., 2013) is nearly similar to our study. Species diversity depends upon land use and the enumeration method. Tang *et al*. (2016), Lamichhane *et al*. (2010), Kumar (2011); Kharal & Oli (2009); Oli *et al*. (2015) found fewer because the study was carried out only on street trees, home gardens, and farmlands. Similarly, Baral *et al*. (2013) also found fewer species in home gardens, roadside plantations, silvopasture (private plantations), and agri-silviculture respectively. By the enumeration of all vascular plants, Cornelis & Hermy (2004) and Wang, *et al*. (2020) recorded more species and generic diversity in urban and suburban parks in Flanders, Belgium, and Shanghai, China respectively. But in the study of living fences only, Thompson *et al*. (2010) found fewer species in the urban and suburban gardens in Khartoum, Sudan. Due to the enumeration of all vascular plants, Vakhlamova *et al*. (2014) reported a slightly higher total number of species in urban–the rural gradient in Kazakhstan where he also found an increasing trend of species richness from urban to rural areas. The general trend of species richness shows that it declines linearly from rural areas to urban ones (Ranta & Viljanen, 2011). We also find this trend in our study where species richness per hectare was higher in the rural stratum than in the urban and suburban strata. But our study showed a higher number of species in the urban stratum followed by suburban and rural strata. This is because planted trees are found in larger numbers in offices, schools, colleges, home gardens, parks, museums, roads, etc. Wang *et al*. (2020); Schwoertzig *et al*. (2016a) found similar results to our study: an increasing trend in the number of species with increasing urbanization. But Ranta & Viljanen (2011) found a suburban peak of species richness, i.e., the highest species richness in suburban areas in the city of Tampere, Finland. This is due to the homogeneity of coniferous trees in rural areas of Finland.

Tree species could be native or exotic. A slightly high percentage of native species were found in the study area. Similar results were also reported on farms in Mount Kenya (Kehlenbeck, 2011) which is due to altitudinal gradient, in agroforestry in Meru, Mount Kenya (Lengkeek *et al*., 2005) which is due to the dominance of indigenous coffee plants, and in Kazakhstan (Vakhlamova *et al*., 2014) which is due to the enumeration of all vascular plants on grassland as dominating land use. But, by the enumeration of all vascular plants, Wang (2020) found lesser native species in Shanghai, China. This might be due to Shanghai being the most populous and industrial urban area with more ornamental plants. Though urbanization is believed to be harmful to the loss of native tree species, such species were found more in the suburban stratum than in urban and rural strata in the study area. This fact is supported by the findings of Kuhn & Klotz

(2006) in Germany where the ‘‘most urbanized’’ cells are randomly distributed. Vakhlamova *et al*. (2014), on the other hand, reported an increasing number of native species from urban to rural areas in Kazakhstan. This is due to a relatively short period of urban development in Kazakhstan. Land use types also affect the ratio of indigenous tree species over exotic ones (Nerfa & Rhemtulla, 2019).

Although a higher tree density was found in the suburban stratum in the present study, there was no significant variation across the strata. TOFs density was less in the Nawalparasi district where the urban stratum had higher tree density than the rural (Kharal *et al*., 2008). Low TOFs density was also shown in Morang District where the urban stratum had higher tree density than the rural areas (DFRS, 2007). This may be due to the methodology of counting trees with DBH > 10 cm only. The average tree density was much higher in Dhaka, Bangladesh (Jaman *et al*., 2020) which is due to the enumeration of all the plants, regardless of minimum DBH requirements. But average tree density and species number were less in Southern Kerala, India (Kunhamu *et al*., 2015). This is due to the study including only trees in large, medium, and small peri-urban home gardens. The variation of tree density per parcel was higher in private residential urban forest structures where all plants with ≥ 2.5cm DBH were enumerated (Schmitt-Harsh *et al*., 2013).

The dominance of tree species and their importance varies in different areas and land uses. *G. robusta* was abundantly found on the streets and was the most dominant species in the entire study area. Due to plantation for use as timber, *Tectona grandis* had higher IVI in agroforestry systems in Andongrejo Village, Jember Regency, East Java (Hartoyo *et al*., 2020). With the enumeration of trees with >10 cm DBH only, Mandal & Joshi (2014) found higher IVI of *S. robusta* in the forests of Selaquie Jhajra range, Thano range, and Asarori range respectively of Doon Valley, Western Himalaya, India. Similarly, Maharjan *et al*. (2016-18) in the Baghmara Buffer Zone Community Forest, Chitwan, Nepal, and Rawal & Subedi (2022) in the community-managed forest of the Mid-Western Hilly Region, Nepal found high IVI values. This might be due to the enumeration of all trees regardless of DBH in the study. With the same DBH criteria, Giriraj *et al*. (2008) in the tropical wet evergreen forests of the western ghats, India, and Ajayi & Obi (2015) in Cross River National Park, Nigeria reported lower IVI values. Dominant species were *C. camphora*, *P. roxburghii*, and *B. nepalensis* in urban, suburban, and rural strata respectively. Such variations within the study area were due to the plantation of *C. camphora* on the streets by the Government and other organizations in the urban stratum; the plantation of *P. roxburghii* along the roads and woodlots in the suburban stratum; and the plantation and natural vegetation of *B. nepalensis* in the rural stratum. The dominant tree species types and IVI were different in the Sacred Groves in the study area. *Neolitsea cuipala* was the dominant tree species with higher IVI in a single forest type in the Bajrabarahi Sacred Grove while *S. wallichii*, *Rapanea capitellata,* and *Quercus glauca* were the most dominant tree species with higher IVI in three forest types respectively in Pashupati Sacred Grove in the study area (Shrestha *et al*., 2015). Similarly, Chhetri & Shrestha (2019) reported higher values of IVI in *Eurya acuminate* in a lower temperate zone, *Lithocarpus pachyphylla* in a middle temperate forest, and *Lithocarpus pachyphylla* in the upper temperate forest. This might be due to the enumeration of all vascular plants with ≥ 10 cm DBH only. Similarly, in the study of tree/shrub species on farms in North-eastern Ethiopia, Muche *et al*. (2022) found low dominancy of *Acacia seyal* at low and mid-altitude plots and *Eucalyptus globulus* at highlands respectively.

As compared to our study, the average TOFs height (9 m) was higher, but the average DBH (24 cm) was similar as reported in Nawalparasi District, Nepal (Kharal *et al*., 2008). This is due to the dominance of *Dalbegia sissoo*, *Mangifera indica*, and *Melia azedarach* in Nawalparasi. Conversely, both average TOFs height (6 m) and average DBH (20 cm) were lower in Morang district, Nepal (DFRS, 2007). This is due to the dominance of *D. sissoo*, *Albizia indica*, *and Saraca indica* there. Similarly, the average tree height and DBH in the street trees in the Pokhara and Bharatpur Districts of Nepal were high (Lamichhane *et al*., 2010). The frequency of *D. sissoo*, *S. indica*, *C. camphora*, and *M. azedarach* was higher in both Pokhara and Bharatpur. Due to the enumeration of trees in fenced areas only, the tree height range was lower in urban and peri-urban gardens of Khartoum, Sudan. (Thompson *et al*., 2010). As the trees were not very mature, the mean DBH values were lower in urban parks and playground edge plantations (Jaman *et al*., 2020). The maturity of the trees is also affected by the management of the land. Mean DBH values were lower in fuelwood harvesting sites than in reference sites (Nerfa & Rhemtulla, 2019). Average tree height and DBH were found higher in Bajrabarahi Sacred Grove and Pashupati Sacred Grove in Kathmandu Valley (Shrestha *et al*., 2015).

There were variations in phytomass carbon, with the urban stratum showing the highest values in the present study. The value of phytomass carbon stock differs depending on differences in land use. Due to the calculation of above-ground carbon only on farms, the mean values of phytomass carbon of three different altitudinal zones in upland, midland, and lowland zones in Mount Kilimanjaro, Tanzania (Mathew *et al*., 2016) were lower than our findings. Mean phytomass carbon stock in coffee agroforestry in eastern Ethiopia (Toru & Kibret, 2019), in TOFs along roads and agroforestry in the semi-arid region of southern Haryana (Singh & Chand, 2012) were lower; tree density was also lower. Similarly, Baral *et al*. (2013) also reported less phytomass carbon in the home garden, roadside plantation, and agri-silviculture respectively in Kanchanpur District. In contrast, home gardens in Cooch Behar, Jalpaiguri, and Siliguri, West Bengal with more tree density showed comparatively higher average phytomass carbon stock (Subba *et al*., 2018). But Mandal *et al*. (2015) reported similar average phytomass carbon stock in rich and medium households in Sahodawa and Pipara, Mahottari District, Nepal. This is due to higher tree density. Because of good management, reference sites had higher mean AGB than fuelwood harvesting sites (Nerfa & Rhemtulla, 2019). Due to higher numbers of species and undisturbed and mature sites, higher mean above-ground carbon stocks were observed in botanical gardens than in urban parks in Dhaka, Bangladesh (Jaman *et al*., 2020). The average phytomass carbon stock is higher in the mid-hills mountain forests (82.13 t ha^{-1}) (DFRS, 2015) than that in the study area. This is due to higher tree density and a higher number of species in the mid-hills forests. Similarly, due to higher tree density, Shrestha *et al*. (2019) also found higher total average carbon stock for five forest types in Pashupati Sacred Grove and Bajrabarahi Sacred Grove. Due to the dominance of large-sized tree species such as *Ginkgo biloba* and *Populus* sp., Tang *et al*. (2016) reported comparatively higher values of vegetation carbon storage in street trees in the urban districts of Beijing, China. The variation of Plant C-stock per parcel was lower in urban forestry structures (Schmitt-Harsh *et al*., 2013). Similarly, Kleinn *et al*. (2015) reported lower average biomass stocks for TOFs in Cameroon and the Philippines where Palm trees with DBH ≥ 10 cm were enumerated. In contrast, Guo *et al*. (2014) found high biomass carbon stocks in TOFs in China in 2004–2008. This might be due to the assessment of trees in woodlands, shrubberies, and non-forest land in that study. Average C-stock was comparatively lower in the Molise region, Central Italy Marchetti *et al*. (2018). This is due to the estimation of above-ground average C-stock only. In the present study, the phytomass carbon stock had a significant positive relation with species richness, which is consistent with the trend reported for the tropical hills of India (Pragasan, 2022), in a medium sized urban area in the Midwest, United States (Schmitt-Harsh *et al*., 2013) and Kanchanpur District, Nepal (Baral *et al*., 2013).

Due to a lack of global data on SOC in urban-rural gradients, the discussion is done with the help of available data. Mathew *et al*. (2016) and Toru & Kibret (2019) found higher mean values SOC in the agroforests which might be due to multi-story agroforests with coffee as the dominant tree species. Dengiz *et al*. (2015) reported quite similar mean SOC density. It might be due to the haplustept type of soil in both cases. Amanuel *et al*., (2018), Mulat *et al*., (2018), Ghimire *et al*., (2018), Sahoo *et al*., (2019), and Pardona *et al*., (2017) found low mean SOC where trees were distantly planted and cereals were the dominant crop plants which were used for different purposes so that only small portion of crop residue and organic matter was returned to the soil. Baral *et al*. (2013) found less SOC which might be due to less tree density. Dhakal *et al*. (2010) also reported low average SOC. It might due to crop rotation as paddy-fallow in Khet and land leased to a brick factory. But Adhikari *et al*. (2019) found high average SOC stock which might be due to the Spodosol type of soil profile. Gupta & Sharma (2011) reported lower mean SOC in woodlots. It might be due to high soil depth. Subba *et al*. (2018) reported less SOC in homesteads. This might be due to high rainfall leaching up organic matter. Baral *et al*. (2013) found less SOC in roadside plantations which might be due to less species number and less tree diversity. Mandal *et al*. (2013) found low SOC. Similarly, Ghimire *et al*. (2018) reported low average SOC stock. As maize and potato are the main crops, most of the plants after harvest were not mixed in the soil so that there is less return of organic matter to the soil. Dhakal *et al*. (2010) also reported low average SOC which might be due to crop rotation of maize-millet–fallow.

3.5 Conclusion

The study reported 150 species and 111 genera belonging to 57 plant families in the TOFs of Kathmandu Valley. Species richness was higher in rural areas compared to suburban and urban areas. Moreover, tree density was higher in suburban areas. Tree height and phytomass carbon stocks were highest in urban areas compared to other strata. Although the number of species found in the study area was less than those in the Middle Hill Mountain forests of Nepal, the observed diversity of tree species in these TOFs play a significant role in biodiversity conservation, while also supplying subsistence materials to the urban-rural community. Existing urban forestry, in this context, is very much important while new constructions of urban forests are equally crucial. Urbanization is said to be harmful to the diversity of native plant species. But due to plantation culture, native species were found more in the urban stratum. Additionally, while rapid urbanization is said to be detrimental to biodiversity, the TOFs of the urban stratum in Kathmandu Valley appears to be of great importance for carbon storage due to the higher average height and DBH of trees there. Besides, TOFs also help to maintain urban greenery and conservation of native tree species. The database of such assessments provides opportunities for framing significant policy or management decisions about the relationship between carbon storage and species diversity. TOFs play very important role in SOC storage. Based on strata, rural TOFs are important as they stored the highest average SOC than the suburban and urban. Even under poor management, the soil has higher carbon stock. It also highlights the necessity to implement conservation-based production systems with the inclusion of woody perennials.

CHAPTER 4[2]

TREE-RELATED MICROHABITATS AND TREES OUTSIDE THE FORESTS ALONG THE URBAN-RURAL GRADIENT IN KATHMANDU VALLEY

4.1 Introduction

Tree-related microhabitats **(**TreMs) are distinct structures present on trees that act as a habitat for one or more species during at least a part of their life cycle to develop, feed, shelter, or breed (Larrieu *et al*., 2018). Tree microhabitats are not found in all trees (Larrieu *et al*., 2018). The number and types of microhabitats per tree vary depending upon the tree species and the size of the tree because this increase markedly with increased tree diameter (Vuidot *et al*., 2011; Courbaud *et al*., 2021). Therefore, very large trees are significant because they could host almost all microhabitat types (Larrieu & Cabanettes, 2012). But the chances of casualties due to such large sized should be kept in mind (Korkjas *et al*., 2021). Generally, invertebrates or vertebrates make a habitat on trees (Larrieu *et al*., 2018).

TreMs come under supporting ecosystem service (TEEB, 2010) which also helps in biodiversity. Depending upon the landscape, the frequency of occurrence of the microhabitat on either living or dead trees varies (Butler *et al*., 2020). Due to the limited life span, however, a new microhabitat can be formed after the death or decay of one type of microhabitat (Butler *et al*., 2021). Though TreMs are not the main indicator for species richness, they can be considered better than other established indicators (Noss, 1990; Magg *et al*., 2019).

TreMs as a surrogate biodiversity indicator, a new concept is of special interest (Asbeck *et al*., 2021; Martin *et al*., 2022). TreMs such as dendrotelms (Kitching, 1971) and cavities (Wesołowski, 2007) have been well studied but several other types are not studied yet, implying the existence of many knowledge gaps (Martin *et al*., 2022). Though there is growing research on TreMs, especially in forest ecosystems (Winter &

[2] **Shrestha, B.,** Sharma, B. K., and Yadav, R. K. P. (2022). Tree-related Microhabitats and Trees Outside Forest along the Urban-Rural Gradient in Kathmandu Valley. *Journal of Plant Resources - Special Issue,* **20**(1): 12-28. https://doi.org/10.3126/bdpr.v20i2.56949

Moller, 2008; Vuidot *et al*., 2011; Regnery *et al*., 2013; Großmann *et al*., 2020), yet all TreMs are not studied due to inconsistency in TreMs definitions in the available literature. Furthermore, some TreMs are rarely recorded (Larrieu *et al*., 2021). But now experts have developed a typology of TreMs in forestry practice (Butler *et al*., 2021) as 7 forms, 15 groups, and 47 types (Larrieu *et al*., 2018). The seven forms are - 1. Cavities, 2. Injuries expose sapwood, 3. Crown deadwood, 4. Excrescences, 5. Fungal fruiting bodies and slime molds, 6. Epiphytic and epixylic structures and 7. Exudates.
Another aspect of TreM is the co-occurrence patterns which are poorly investigated. It is the co-dependency of more than one organism on the same tree, the crucial drivers of which are the tree species, DBH, and the state of the tree (Larrieu & Cabanettes, 2012; Larrieu *et al*., 2014; Paillet *et al*., 2017; Courbaud *et al*., 2021).

TreMs such as dendrothelms (Kitching, 1971) and cavities (Wesołowski, 2007) have been well studied but several other types are not studied yet, implying the existence of many knowledge gaps (Martin *et al*., 2022). The retention of trees as TreMs in forests managed for timber production is essential for fulfilling the objectives of biodiversity conservation (Basile *et al*., 2020; Frey *et al*., 2020). Furthermore, biodiversity conservation should be done by keeping in mind the future of TreM formation too (Courbaud *et al*., 2017; Courbaud *et al*., 2021). Studying and assessment of these by providing guidelines to the concerned can play an important role in the sustainable management of forest ecosystems regarding biodiversity conservation (Khanalizadeh *et al*., 2020; Martin *et al*., 2022).

Trees Outside Forests (TOFs) are landscape types (Bellefontaine *et al*., 2002) defined by FAO (1998) as "the plants on the land of area less than 0.5 ha. TOFs include both trees and shrubs and trees ranging from a single discrete tree to systematically managed trees (Kleinn, 2000; Foresta *et al*., 2013). Nowadays, due to many issues, urban areas have expanded rapidly so the inventory efforts of assessments of all the trees both within and outside forest areas across the urban–rural gradient (Westfall *et al*., 2018). Urbanization is one of the crucial factors for decline in plant diversity at the local and regional scales (Wang *et al*., 2020). The urban-rural gradient explores the changes in plants from the rural area to the core urban (Ranta & Viljanen, 2011).

In the context of TreMs in Kathmandu Valley, Twenty-three species of orchids with 13 genera were reported on 42 host tree species from Kathmandu Valley (Adhikari *et al*., 2012). Mistletoes are common on trees in the valley (Devkota & Acharya, 1997). Thapa *et al*. (2012) reported tree as one, out of five habitat types for bats.

Trees are important for the likelihood of future TreM formations which helps in biodiversity conservation (Courbaud *et al*., 2021). TreMs assessments have been done in developed countries. Few research has been done on species diversity, DBH class and volumes of TOFs in Nepal. Similarly, few assessments on cavities have been done in Nepal but in Terai forests only. Assessment TreMs on TOFs is new to Nepal. Thus, to assess the TreMs abundance and richness on TOFs along the urban-rural gradient in Kathmandu Valley, this research had been done. This will provide the baseline data useful for microhabitats as well as biodiversity conservation.

4.2 Materials and methods

4.2.1 Study area

Same as chapter 2.

4.2.2 Methods

4.2.2.1 Site selection and sampling

Identification of sampling plots and sampling methods up to tree level characteristics were same as in Chapter 2. Other organisms making one or more habitats or support on the TOFs species were also enumerated. Nest and cavities if present were noted along with the organism types. Sap run if the present was also recorded. Methods for plant identification, vernacular names, scientific names were also same as in Chapter 2.

The collected lichen samples were segregated according to their growth forms and further grouped according to the type of fruiting bodies. Then the lichen species were identified through morphological, and anatomical studies with the help of micro and macro-lichens identification keys of Awasthi (2007), Baniya & Bhatta (2021), and Baniya *et al*. (2022). Fungi identification was done with the help of relevant literature Websites (biodiversity library.org; Index fungorum; Jstor.org; Mycobank.org; Scircus; tropicos.org; Agaricus in the Pacific Northwest; Boletes in the Pacific Northwest) and Singer (1986). Similarly, orchids were identified through morphological studies with the help of Rokaya *et al*. (2013), Rajbhandari (2015); Rajbhandari & Rai (2017).

4.2.2.2 Statistical analysis

The means and standard deviation of test variables were estimated following standard procedures. Variables related to TreMs were subjected to the test of normality and were found not normal. Kruskal-Wallis tests were applied for multiple comparisons using SPSS (26).

4.3 Results

4.3.1 TreMs in the study area

TOFs play an important role in the habitat conservation of ferns, mosses, lichens, fungi, and other phanerogams including orchids and parasitic plants. While TOFs provide support to the climber plants, these are equally important for the habitat conservation of animals, insects and birds. In this study, a total of 6210 individuals (density = 236.35 ha^{-1}) of TOFs with 150 species were recorded in the study area. Out of which 1038 individuals (density = 39.51 ha^{-1}) of TOFs representing 64 species were found to serve as TreMs (Table 15) in 150 plots. TreMs types per plot varied from 1 to 7. Some TOFs had more than one habitant type. Due to co-occurrence, habitant type per tree varied from 1 to 6 (Table 15). Six habitants were found in only one tree of *Cinnamomum camphora* with 8.6 m height and 75 cm DBH.

Table 15: Number and density of TOFs with TreMs, numbers of trees with habitant numbers in the study area

Number of TOFs with TreMs	Density of TOFs with TreMs (ha^{-1})	6 habitants	5 habitants	4 habitants	3 habitants	2 habitants	1 habitant
1038	39.51	1	4	8	67	293	665

Tree height and DBH are the main elements for TreMs distribution. Height and DBH of the habitat trees in our study area varied from 1.5 to 26 m with an average of 7.12 ± 3.63 m. and 5 to 181 cm with an average of 29.86 ± 23.53 cm respectively (Table 16).

A total of 4 forms, 5 groups, and 14 types were recorded in the study area (Table 17). The number of individuals and species of TOFs as TreMs with habitat types recorded are described below.

Seventeen individuals of 13 TOFs species had 17 cavities without animal signs (Table18, Figure 14 A) in 14 plots. Cavity as the microhabitat is the most studied TreMs worldwide. Height and DBH of the cavity trees varied from 2.50 to 15 m with an average of 8.55 ± 6.40 and 18.90 to 95.30 cm with an average of 44.41 ± 23.03 cm respectively (Table 16).

Table 16: Minimum, maximum, and average height and DBH of trees with TreMs and cavity trees in the study area

TOFs with TreMs (n=1038)			**Cavity tree (n=17)**		
	Height (m)	**DBH (cm)**		**Height (m)**	**DBH (cm)**
Minimum	1.5	5	Minimum	2.5	18.9
Maximum	26	181	Maximum	15	95.3
Average ± sd	7.12 ± 3.63	29.86 ± 23.53	Average ± sd	8.55 ± 6.40	44.41 ± 23.03

Table 17: Forms, groups, and types of TreMs found in the study area.

SN	**Form**	**Group**	**Type**
1	Cavities	Rot holes	Trunk base rot hole
2	Fruiting bodies of saproxylic fungi and slime molds	Ephemeral fungal fruiting bodies and slime molds	Perennial polypores
			Annual polypores
			Cortiaceae
3	Epiphytic, epixylic, and parasitic structures	Epiphytic or parasitic crypto- and phanerogams	Bryophytes
			Lichens
			Ivy
			Ferns
			Mistletoe
			Orchids
			Other phanerogams
		Nests	Vertebrate nest
			Invertebrate nest
4	Fresh exudates	Fresh exudates	Sap run

Eight fungi species (7 of Basidiomycetes and 1 of Corticiaceae) were enumerated in 12 individuals of 6 TOFs species (Table 19) in 7 plots. Perennial and annual polypores were also found (Figures 14 B and 14 C). Mosses were found on 332 individuals of 31 TOFs species (Table 20) in 54 plots. Fifteen lichen species were found on 377 individuals of 42 TOFs species (Table 21, Figure 14 D) in 46 plots. Eleven ivy (climber) species were found on 65 individuals of 27 TOFs species (Table 22, Figure 14 E) in 28 plots. Five fern species were found on 166 individuals of 35 TOFs species (Table 23, Figure 14 F) in 49 plots. Two mistletoe as epiphytic parasitic species were found on 2 individuals of 2 TOFs species (Table 24) in 2 plots. Five orchid species were found on 36 individuals of 22 TOFs species (Table 25, Figure 15 G) in 16 plots. Twelve other phanerogam species were found on 40 individuals of 15 TOFs species (Table 26, figure 15 H) in 32 plots.

Similarly, 199 bird nests were found on 139 individuals of 26 TOFs species (Table 18, Figure 15 I) in 86 plots. One hundred and fifteen individuals of 25 tree species had one nest in 130 plots, 19 individuals of 11 tree species had two nests in 16 plots, 9 individuals of 6 tree species had three nests in 7 plots and 1 individual of 1 tree species had four nests in 1 plot. Eight individuals of 4 tree species had one ant nest, 1 individual of 1 tree species had more than one ant nest on them (Table 18, Figure 15 J) while 3 individuals of 3 tree species had one beehive in each (Table 18, Figure 15 K).

Twenty-seven individuals of 9 TOFs species had sap runs (Table 18, Figure 15 L) in 13 plots.

Besides the habitats, 7 live animal species were also found in the study area (Table 27).

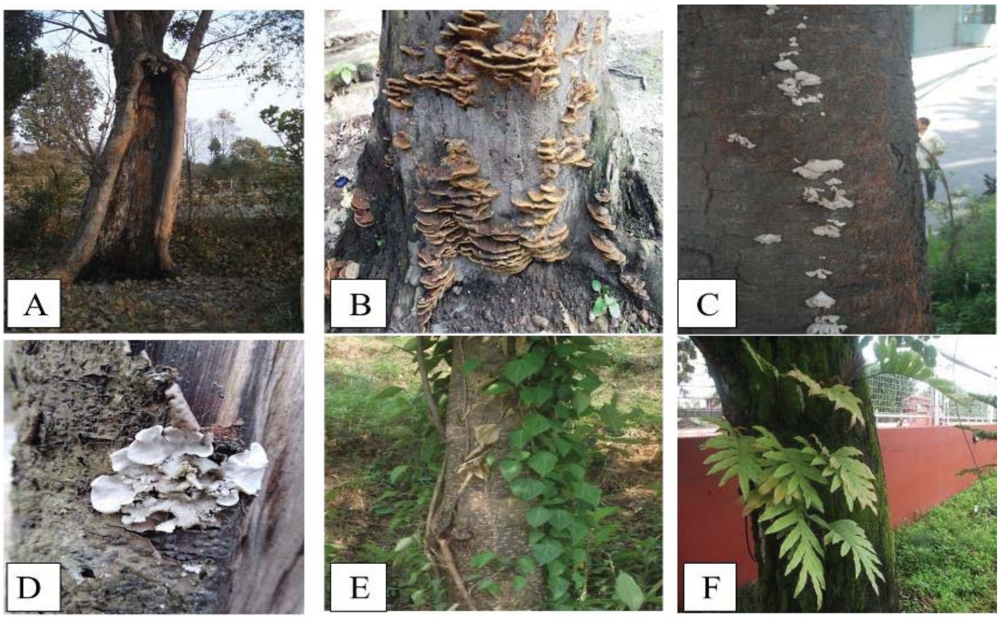

Figure 14: TreMs for A- cavity, B- fungi (Perennial polypore), C- fungi (Annual polypore), D- lichens, E- ivy, and F- ferns.

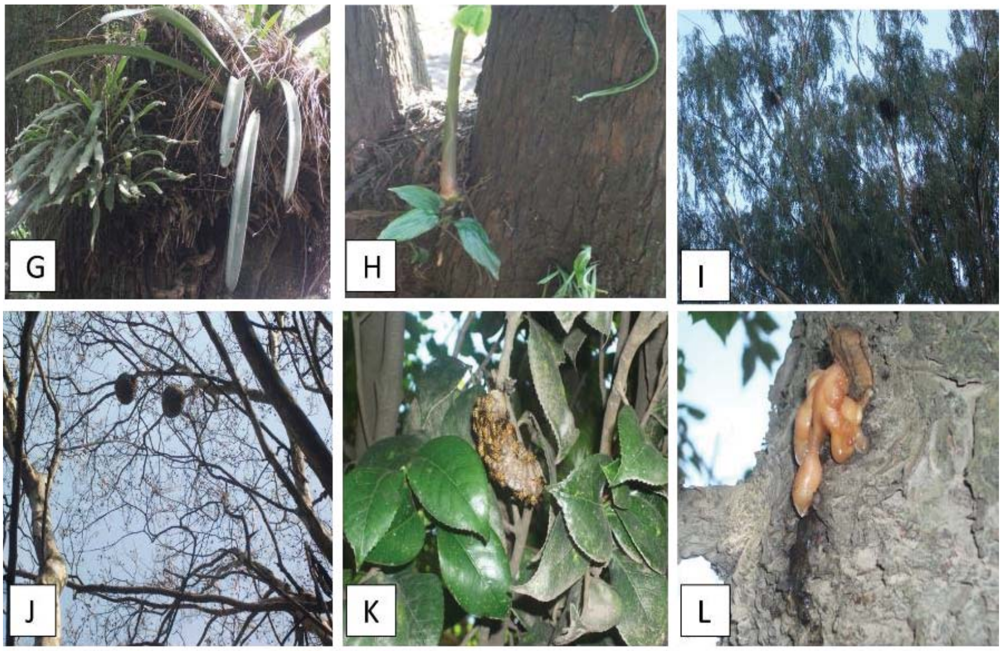

Figure 15: TreMs for G- orchids, H- other phanerogams, I- birds nest, J- ant nest, K- bee hive, and L- sap run.

Table 18: TOFs species showing the presence of a cavity, nests, ant nest, beehive, and sap run in the study area

SN	TOFs species	Cavity	1 nest	2 nests	3 nests	4 nests	Ant nest	Beehive	Sap run
1	*Alnus nepalensis* D. Don		+						
2	*Araucaria bidwillii* Hook.		+						
3	*Araucaria heterophylla* (Salisb.) Franco		+						
4	*Bougainvillea glabra* Choisy	+							
5	*Callistemon citrinus* (curtis) Skeels	+	+	+					+
6	*Camellia japonica* L.							+	
7	*Casuarina equisetifolia* L.	+							
8	*Cedrus deodara* (Roxb. ex D. Don) G. Don								+
9	*Celtis australis* L.		+	+	+		+		
10	*Choerospondi asaxillaris* (Roxb.) B.L.Burtt		+						
11	*Cinnamomum camphora* (L.) J. Presl		+	+	+	+			+
12	*Dalbergia sissoo* Roxb.		+						
13	*Eucalyptus camaldulensis* Dehn.		+	+	+				
14	*Ficus benghalensis* L.		+						
15	*Ficus benjamina* L.		+						
16	*Ficus elastica* Roxb.		+						
17	*Ficus religeosa* L.		+	+	+				
18	*Grevillea robusta* A. Cunn. ex R. Br.		+	+			+	+	+
19	*Jacaranda mimosifolia* D. Don	+	+		+				+
20	*Juglans nigra* L.		+						
21	*Juglans regia* L.	+							
22	*Lagerstroemia indica* L.		+				+		
23	*Litsea monopetala* (Roxb.) Pers.			+					
24	*Melia azedarch* L.		+	+					

25	*Magnolia champaka* L.							+
26	*Myrica esculenta* Buch-Ham. ex D. Don	+						
27	*Persea americana* Mill.		+					
28	*Pinus roxburghii* Sarg.		+					+
29	*Populus jacquemontiana* Dode.	+	+	+	+			+
30	*Prunus domestica* L.	+						
31	*Pyrus pashia* Buch-Ham. ex D. Don.	+	+					
32	*Pyrus pyrifolia* (Burn.) Nak.	+						
33	*Rhododendron arboreum* Smith	+						
34	*Salix tetrasperma* Roxb.	+	+					
35	*Syzygium cumini* (L.) Skeels		+	+				
36	*Thuja orientalis* L.	+	+	+		+		+
37	*Ziziphus incurva* Roxb.						+	

Table 19: TOFs species as TreMs for fungi in the study area

SN	TOFs species	SN	Fungi species
1	*Buddleja asiatica* Lour.	1	*Coriolus* sp.
2	*Grevillea robusta* A. Cunn. ex R. Br.	2	*Fomes fomentarius* L. (Fr.)
3	*Litsea monopetala* (Roxb.) Pers.	3	*Inonotus radiates* (Sowerby) P. Karst
4	*Populus jacquemontiana* Dode.	4	*Schizophyllum commune* Fr.
5	*Pyrus pashia* Buch-Ham. ex D. Don.	5	*Stereum hirsutum* (Willd.) Pers.
6	*Thuja orientalis* L.	6	*Stereopsis* sp.
		7	*Tyromyces caesius* (Schrad.) Murrill.
		8	Species belonging to the Corticiaceae family

Table 20: TOFs species as TreMs for moss in the study area

SN	TOFs species		
1.	*Alnus nepalensis* D. Don	17.	*Lagerstroemia indica* L.
2.	*Albizia julibrissin* Durazz.	18.	*Litsea monopetala* (Roxb.) Pers.
3.	*Borassus flabellifer* L.	19.	*Mangifera indica* L.
4.	*Buddleja asiatica* Lour.	20.	*Manglietia insignis* (Wall.) Blume
5.	*Callistemon citrinus* (curtis) Skeels	21.	*Melia azedarch* L.
6.	*Casuarina equisetifolia* L.	22.	*Nyctanthes arbor-tristis* L.
7.	*Celtis australis* L.	23.	*Phoenix humilis* Royle.
8.	*Choerospondias axillaris*(Roxb.) B. L. Burtt	24.	*Pinus roxburghii* Sarg.
9.	*Cinnamomum camphora* (L.) J. Presl	25.	*Populus jacquemontiana* Dode.
10.	*Eucalyptus camaldulensis* Dehn.	26.	*Pyrus pyrifolia* (Burn.) Nak.
11.	*Ficus benjamina* L.	27.	*Salix tetrasperma* Roxb.
12.	*Ficus religeosa* L.	28.	*Schima wallichii* (DC.) Korth.
13.	*Grevillea robusta* A. Cunn. ex R. Br.	29.	*Syzigium cumini* (L) Skeels
14.	*Jacaranda mimosifolia* D. Don	30.	*Syzigium jambos* (L.) Alston
15.	*Juglans nigra* L.	31.	*Thuja orientalis* L.
16.	*Juniperus recurva* Buch-Ham. ex D. Don		

Table 21: TOFs species as TreMs for lichens in the study area

SN	TOFs species	SN	Lichen species
1	*Alnus nepalensis* D. Don	1	*Canoparmelia sp.*
2	*Araucaria heterophylla* (Salisb.) Franco	2	*Chrysothrix candelaris* (L.) J. R. Laudon
3	*Borassus flabellifer* L.	3	*Dirinaria aegiliata* (Afzel. ex Ach.) B. J. Moore
4	*Buddleja asiatica* Lour.	4	*Graphis stenotera* Vain.
5	*Caryota urens* L.	5	*Candelaria concolor* (Ach.) Flot.
6	*Celtis australis* L.	6	*Herpothallon* sp.
7	*Choerospondias axillaris* (Roxb.) B.L.Burtt	7	*Hyperphyscia adglutinata* (C. Knight) Mull. Arg.
8	*Cinnamomum camphora* (L.) J. Presl	8	*Lepraria* sp.
9	*Citrus aurantifolia* (Christm) Swingle	9	*Parmotrema praesorediosum* (Nyl) Hale.
10	*Citrus maxima* (Burm.) Herr.	10	*Pertusaria* sp.
11	*Eucalyptus camaldulensis* Dehn.	11	*Physcia crispa* (Nyl)

12	*Ficus religiosa* L.	12	*Physcia dubia* (Hoffm.) Lettau
13	*Fraxinus floribunda* Wall.	13	*Physcia sorediosa* (Vain.) Lynge
14	*Grevillea robusta* A. Cunn. ex R. Br.	14	*Pyrenula* sp.
15	*Ilex excelsa* (Wall.) Hook. Fil.	15	*Pyxine* sp.
16	*Jacaranda mimosifolia* D. Don		
17	*Juglans regia* L.		
18	*Juniperus recurve* Buch-Ham. ex D. Don		
19	*Lagerstroemia indica* L.		
20	*Litchi chinensis* Sonner		
21	*Litsea monopetala* (Roxb.) Pers.		
22	*Magnolia soulangeana* Soul.		
23	*Mangifera indica* L.		
24	*Manglietia insignis* (Wall.) Blume		
25	*Magnolia fuscata* Bl.		
26	*Morus alba* L.		
27	*Myrica esculenta* Buch-Ham. ex D. Don		
28	*Nerium indicum* Miller		
29	*Nyctanthes arbor-tristis* L.		
30	*Persea americana* Mill.		
31	*Persea duthiei* (King ex Hook. F.) Kosterm.		
32	*Phoenix humilis* Royle.		
33	*Pinus roxburghii* Sarg.		
34	*Prunus cerasoides* D. Don		
35	*Prunus domestica* L.		
36	*Prunus persica* (L.) Batsch		
37	*Pyrus pyrifolia* (Burn.) Nak.		
38	*Quercus glauca* Thumb.		
39	*Schefflera impress* (C. B. Clarke) Harms		
40	*Schima wallichii* (DC.) Korth.		
41	*Syzygium jambos* (L.) Alston		
42	*Thuja orientalis* L.		

Table 22: TOFs species as TreMs for ivy (climbers) in the study area

SN	TOFs species	SN	Climber species
1	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1	*Cucurbita maxima* Duchesne
2	*Albizia julibrissin* Durazz.	2	*Dioscore aalata* L.
3	*Alnus nepalensis* D. Don	3	*Diplocyclos palmatus* (L.) C. Jeffrey
4	*Araucaria heterophylla* (Salisb.) Franco	4	*Hedera nepalensis* K. Koch
5	*Bauhinia variegata* L.	5	*Lagenaria siceraria* (Molina) Standl.
6	*Callistemon citrinus* (curtis) Skeels	6	*Macfadyena unguis-cati* (L.) Miers
7	*Celtis australis* L.	7	*Monstera deliciosa* Liebm.
8	*Choerospondias axillaris* (Roxb.) B.L.Burtt	8	*Oplismenus burmannii* (Retz.) P. Beauv.
9	*Cinnamomum camphora* (L.) J. Presl	9	*Sechium edule* (Jacq.) Sw.
10	*Citrus maxima* (Burm.) Herr.	10	*Syngonium podophyllum* Schott
11	*Eucalyptus camaldulensis* Dehn.	11	*Bougainvillea glabra* Choisy
12	*Ficus lacor* Buch-Ham.		
13	*Ficus semicordata* Buch- Ham. ex Sm.		
14	*Grevillea robusta* A. Cunn. ex R. Br.		
15	*Jacaranda mimosifolia* D. Don		
16	*Melia azedarach* L.		
17	*Magnolia champaka* L.		
18	*Phoenix humilis* Royle.		
19	*Pinus roxburghii* Sarg.		
20	*Platanu sorientalis* L.		
21	*Prunus cerasoides* D. Don		
22	*Prunus domestica* L.		
23	*Prunus persica* (L.) Batsch		
24	*Psidium guajava* L.		
25	*Pyrus pashia* Buch-Ham. ex D. Don.		
26	*Pyru spyrifolia* (Burn.) Nak.		
27	*Thuja orientalis* L.		

Table 23: TOFs species as TreMs for ferns in the study area

SN	TOFs species	SN	Fern species
1	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1	*Drynaria* sp.
2	*Albizia julibrissin* Durazz.	2	*Dryopteris* sp.
3	*Araucaria heterophylla* (Salisb.) Franco	3	*Microsorum* sp.
4	*Areca catechu* L.	4	*Nephrolepis* sp.
5	*Buddleja asiatica* Lour.	5	*Onychium japonicum* (Thumb.) Kunze. Nom.
6	*Callistemon citrinus* (curtis) Skeels		
7	*Cassia fistula* L.		
8	*Casuarina equisetifolia* L.		
9	*Celtis australis* L.		
10	*Choerospondias axillaris* (Roxb.) B. L. Burtt		
11	*Cinnamomum camphora* (L.) J. Presl		
12	*Dalbergia sissoo* Roxb.		
13	*Eucalyptus camaldulensis* Dehn.		
14	*Ficus benghalensis* L.		
15	*Grevillea robusta* A. Cunn. ex R. Br.		
16	*Jacaranda mimosifolia* D. Don		
17	*Juglans nigra* L.		
18	*Juglans regia* L.		
19	*Juniperus recurva* Buch-Ham. ex D. Don		
20	*Lagerstroemia indica* L.		
21	*Mangifera indica* L.		
22	*Manglietia insignis* (Wall.) Blume		
23	*Melia azedarach* L.		
24	*Phoenix humilis* Royle.		
25	*Phyllanthus emblica* L.		
26	*Pinus roxburghii* Sarg.		
27	*Populus jacquemontiana* Dode.		
28	*Prunus cerasoides* D. Don		
29	*Psidium guajava* L.		
30	*Pyrus pashia* Buch-Ham. ex D. Don.		

31	*Pyrus pyrifolia* (Burn.) Nak.
32	*Rhododendron arboreum* Smith
33	*Salix tetrasperma* Roxb.
34	*Schima wallichii* (DC.) Korth.
35	*Thuja orientalis* L.

Table 24: TOFs species as TreMs for mistletoe in the study area

SN	TOFs species	SN	Mistletoe species
1	*Callistemon citrinus* (curtis) Skeels	1	*Cuscuta* sp.
2	*Populus jacquemontiana* Dode.	2	*Viscum album* L.

Table 25: TOFs species as TreMs for orchids in the study area

SN	TOFs species	SN	Orchid species
1	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1	*Bulbophyllum* sp.
2	*Albizia julibrissin* Durazz.	2	*Cleisostoma* sp.
3	*Albizia procera*(Roxb.) Benth.	3	*Dendrobium* sp.
4	*Bougainvillea glabra* Choisy	4	*Pholitoda* sp.
5	*Callistemon citrinus* (curtis) Skeels	5	*Vanda* sp.
6	*Celtis australis* L.		
7	*Choerospondias axillaris* (Roxb.) B. L. Burtt		
8	*Cinnamomum camphora* (L.) J. Presl		
9	*Dalbergia sissoo* Roxb.		
10	*Eucalyptus camaldulensis* Dehn.		
11	*Ficus religeosa* L.		
12	*Grevillearo busta* A. Cunn. ex R. Br.		
13	*Jacaranda mimosifolia* D. Don		
14	*Juglans nigra* L.		
15	*Juglans regia* L.		

16	*Juniperus recurva* Buch-Ham. ex D. Don
17	*Litchi chinensis* Sonner
18	*Melia azedarach* L.
19	*Platanus orientalis* L.
20	*Podocarpus neriifolius* D. Don
21	*Prunus cerasoides* D. Don
22	*Thuja orientalis* L.

Table 26: TOFs species as TreMs for other phanerogams in the study area

SN	TOFs species	SN	Other phanerogams
1	*Areca catechu* (L.F.) Willd.	1	*Alnus nepalensis* D. Don
2	*Callistemon citrinus* (curtis) Skeels	2	*Dischidia* sp.
3	*Casuarina equisetifolia* L.	3	*Ficuslacor* Buch-Ham.
4	*Celtis australis* L.	4	*Ficus religiosa* L.
5	*Cinnamomum camphora* (L.) J. Presl	5	*Fragaria* sp.
6	*Eucalyptus camaldulensis* Dehn.	6	*Hedychium coronarium* J. Koenig
7	*Ficus religiosa* L.	7	*Lycopersicum esculentum* L.
8	*Grevillea robusta* A. Cunn. ex R. Br.	8	*Malvaviscus arboreus* Cav.
9	*Jacaranda mimosifolia* D. Don	9	*Mangifera indica* L.
10	*Mangifera indica* L.	10	*Peperomia pellucida* (L.) A. Dietr
11	*Melia azedarach* L.	11	small herbs (unidentified)
12	*Phoenix humilis* Royle.	12	*Solanum aculeatissimum* Jacq.
13	*Prunus cerasoides* D. Don		
14	*Thespesia lampas* (Cav.) Dalz. & Gibs.		
15	*Thuja orientalis* L.		

Table 27: Animal species recorded in the study area

SN	Animal Species	English common name
1	*Cornu aspersum* Muller	Garden snail
2	Caterpillar	Caterpillar
3	*Lasiusniger* L.	Black garden ant
4	*Tamias sp.* Illiger	Squirrel
5	Tarantula	Spider
6	*Apis* sp.	Bee
7	*Corvus splendens* Viellot	Crow

4.3.2 TreMs in the strata

Average numbers of cavities, fungi, mistletoe, other phanerogams, and invertebrate nests were found higher in the urban stratum (Table 28). Average numbers of lichens, vertebrate nests, and sap runs were found higher in the suburban stratum.

Kruskal-Wallis tests of lichens show a significant difference between urban-rural strata ($p > 0.05$) (Table 28). Kruskal-Wallis tests of ferns showed significant differences between urban-suburban strata ($p > 0.05$) (Table 28). Similarly, the same test of other phanerogams showed significant differences between all the strata ($p \leq 0.05$) (Table 28).

The number of vertebrate nests varied from 1 to 4. Kruskal-Wallis tests of vertebrate nests showed a significant difference between urban-rural as well as suburban-rural strata ($p \leq 0.05$) (Table 28).

Table 28: Plotwise average numbers of TreMs types with (±SE) found in the three strata of the study area. Different superscript letters across rows indicate statistical significance at $p \leq 0.05$ (Kruskal-Wallis tests)

SN	TreMs (Forms)	TreMs (Types)	Urban	Suburban	Rural
1	Cavities	Trunk base rot hole	0.09 ± 0.03^{a}	0.07 ± 0.03^{a}	0.08 ± 0.07^{a}
2	Fruiting bodies of saproxylic fungi and slime molds	Annual and perennial polypores of Basidiomycetes, Corticiaceae	0.14 ± 0.06^{a}	0.01 ± 0.01^{a}	-
3	Epiphytic, epixylic, and parasitic structures	Bryophytes (moss)	1.47 ± 0.39^{a}	1.12 ± 0.32^{a}	2.52 ± 0.83^{a}
		Lichens	0.42 ± 0.14^{a}	3.14 ± 1.76^{ab}	2.31 ± 0.71^{b}
		Ivy	0.33 ± 0.10^{a}	0.23 ± 0.09^{a}	0.40 ± 0.24^{a}
		Ferns	0.94 ± 0.24^{a}	0.32 ± 0.12^{b}	1.25 ± 0.5^{ab}
		Mistletoe	0.02 ± 0.02	-	-
		Orchids	0.06 ± 0.02^{a}	0.16 ± 0.76^{a}	0.40 ± 0.23^{a}
		Other phanerogams	0.36 ± 0.08^{a}	0.08 ± 0.03^{b}	0.04 ± 0.03^{c}
		Vertebrate nest	0.55 ± 0.08^{a}	0.63 ± 0.08^{a}	0.19 ± 0.07^{b}
		Invertebrate nest	0.10 ± 0.08^{a}	0.04 ± 0.02^{a}	-
4	Fresh exudates	Sap run	0.14 ± 0.05^{a}	0.21 ± 0.12^{a}	-

4.4 Discussion

After the enumeration of 2482 trees (>20 cm DBH), Winter & Moller (2008) found fewer microhabitat trees (571) in lowland beech forests in Germany. According to Khanalizadeh *et al*. (2020), microhabitats (272) were less of the five microhabitat types but individual trees (3382) were more in Oriental beech (*Fagus orientalis* L.) dominated forests in Iran. Both are due to the enumeration of only the selected microhabitats. But in their international study of temperate and boreal forests from Northern Iran to Western Europe, Larrieu *et al*. (2021) found a quite higher value of 70,958 individual trees of 78 tree species as TreMs in 2052 plots. Similarly, Piechnik *et al*. (2022) also observed a high number of TreMs density (46 ha^{-1}) in the Niepołomice Forest of S.

Poland. It was due to the enumeration of six selected tree species with only > 20 cm DBH in 94 plots covering a 42.30 ha area. Out of 7 forms, 15 groups, and 47 types of TreMs (Larrieu *et al*., 2018), 4 forms, 5 groups, and 14 types were found in the present study (Table 4.3). Vuidot *et al*. (2011) found the presence of more microhabitat types such as ivy, non-woodpecker cavities, conks, woodpecker cavities, canker, dead crown, cracks, bark pockets, bark losses, and bryophytes in five French forests. Larrieu *et al*. (2021) found TreM co-occurrence for 11 TreM groups. He found six co-occurrences between broad leaves and conifers. These variations in our study might be due to the enumeration of more living trees (70,958) including 54,740 broadleaves, and 16,218 conifers from 2,052 plots. Vuidot *et al*. (2011) reported the Oaks with a significantly larger number of microhabitats per tree (2.66) in five French forests. In his survey of trees with > 7.5 cm DBH, Khanalizadeh *et al*. (2020) reported a range of 7.5–170 cm with an average of 33.6 cm.

Similarly, in the study of trees, only > 20 cm DBH, Piechnik, *et al*. (2022) also found a mean DBH of 37 cm. In addition, microhabitat occurrence and DBH have been reported significantly and positively correlated in fir beech trees (Larrieu *et al*., 2012). Larrieu & Cabanettes (2012) found the first microhabitat occurrence at 41 and 60 cm DBH (median values) for beech and fir respectively. But in contrast, all microhabitats including heavy resinosis and resin drops were more abundant in young stands in Douglas-fir forests of different stand ages and management histories in the Pacific Northwest, U.S.A. (Michel & Winter 2009). Michel & Winter (2009) reported cavities as the low abundant microhabitat on Douglas-fir trees. It was due to the high decay-resistant of resinous wood. Vuidot *et al*. (2011) reported the increase of non-woodpecker cavities significantly with tree diameter. Bhusal *et al*. (2015) reported the presence of cavities in 50 trees of eight tree species in the subtropical lowlands of the inner Terai region, south-central Nepal. This higher tree number but lesser species number was due to the study of all cavity types in the Sal forest. They found similar average values of DBH (38.7 and 47.7 cm) of cavity-occurring trees. Woodpecker cavity trees had a higher average DBH value (63.13 cm) in the southern part of the Black Forest (Southwestern Germany) (Basile *et al*., 2020). Hussain *et al*. (2013) also reported a higher number of cavity-bearing trees (34) in a coniferous forest of Dhirkot, Azad Jammu, and Kashmir part of Pakistan which was due to the study of all cavity types in the forest. Michel & Winter (2009) reported drops of resin as the most abundant microhabitat on Douglas-fir trees. It was due to the resinous wood.

In urban areas, there are reports of decreasing lichen abundance due to higher levels of air pollution (Bergamaschi *et al*., 2007). In the case of vertebrate avian richness, there is a reduction with increased urbanization (Chace & Walsh, 2006). Khanalizadeh *et al*. (2020) found the cavity as the most abundant microhabitat type in both managed (16.5 per ha) as well as in recently unmanaged (14.2 per ha) forests. The distribution of cavities depends upon the tree species and tree DBH of different altitudes. Hussain *et al*. (2013) found more tree population (647) but fewer cavity-bearing trees (5.3%) in the upper elevation (2042 m) than less tree population (493) but more cavity-bearing trees (10.0% of trees) in the lower elevation (1066 m). Similarly, average numbers of moss, ivy, ferns, and orchids were found higher in the rural stratum. Vuidot *et al*. (2011) reported a significantly lower occurrence of bryophytes in Fontainebleau than at all the other sites. He stated that the presence of bryophytes increased with a diameter at a higher rate for "other species" than for oaks or fir and spruce.

Vuidot *et al*. (2011) found the presence of only ivy was highest in Auberive (14.3%) which significantly differed from Fontainebleau (2.9%). Michel & Winter (2009), in their study, found a significant difference in the total number of microhabitats/ha only between the clear-cut stands and the managed young, natural mature, and natural old-growth stands, respectively. Based on individual microhabitat types and the total number of microhabitats, Khanalizadeh *et al*. (2020) did not find any significant difference between managed and recently unmanaged forests. Due to a lack of available results, our work cannot provide a complete discussion on microhabitat key factors. We showed that the number and occurrence of microhabitat types were mainly influenced by tree characteristics. Our findings have shown that lichens were the dominating habitant on TOFs, followed by mosses and birds.

4.5 Conclusion

This study provides fundamental information about the importance of both TOFs and TreMs in terms of biodiversity and its conservation in Kathmandu Valley, Nepal. Lichens are the dominating habitants on TOFs, followed by mosses and birds. *C. camphora* as an individual tree of rural stratum served maximum habitat types (6). Micro habitat types might or might not be dependent on the DBH of the tree. Generally, co-occurrence of microhabitat is more common on trees with greater DBH. Microhabitats are also strata-specific because maximum habitat types (7) were found in urban and rural strata. Both urban and rural TOFs contribute significantly to biodiversity conservation because maximum habitat types (7) were found in both strata. These natural gifts should be preserved for the coming generations. So to overcome the disturbances of macro as well as micro habitats caused by the deforestation to meet the rapid urbanization, conservation of existing TOFs and new TOFs plantations are very essential. At the mean time the bad casualties due to mature and large sized trees should be kept in mind.

CHAPTER 5[3]

VALUATION OF TIMBER AND FIREWOOD OF TREES OUTSIDE THE FOREST ALONG THE URBAN–RURAL GRADIENT IN KATHMANDU VALLEY, NEPAL

5.1 Introduction

FAO (1998) has defined trees outside forest (TOFs) as "the trees on the land that fulfills the requirements of forest and other woodlands except that the area is less than 0.5 ha and the canopy is < 10%". For example, scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconut; trees in parks and gardens, around buildings, and in lines along streets, roads, railways, rivers, streams, and canals; and trees in shelterbelts of less than 20 m width and 0.5 ha area. TOFs comprise all trees ranging from a single discrete individual tree to systematically managed trees (Kleinn, 2000). TOFs are prominent features in many landscapes, strata (urban, suburban, and rural) and substrata (linear, clumped, and scattered tree formations) (Baffetta *et al*., 2010; DFRS, 2011). TOFs include both trees as well as shrubs (Foresta *et al*., 2013). Bamboo is a part of TOFs that is merchantable for house construction (Bhusal & Bashyal, 2020).

TOFs have become an important source of timber globally but still, there are no policies related to the management, harvest, transit, and marketing of timber from TOFs (Ghosh & Sinha, 2018). They play significant role in meeting the challenges of resource sustainability, poverty reduction, food security, lessening the pressure on forest resources, conserving farmland, increase agricultural productivity and food supplies (Foresta *et al*., 2013). Besides, TOFs also provide the impetus to the growth of wood-based industries and employment opportunities by increasing the extent of area under forest (FSI, 2003) especially more jobs to rural communities (Asanzi *et al*., 2014). In some cases, total wood production from TOFs is more than that from the forests (Krishnankutty *et al*., 2008). TOFs could serve many ecological and economic

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functions that might be similar to those of forests in different ways and extent (Kleinn, 2000). Wood production is one of them. Wood includes all timber, industrial wood, firewood, and charcoal (Krishnankutty *et al*., 2008). It is still the most widely used fuel source in developing countries (FAO, 1999).

A timber readily harvestable is merchantable timber (Ouattara *et al*., 2014). According to DFRS (2015), a tree can be classified as a quality class A tree (high-quality sound tree) - a live tree that would produce at least one 6 m long saw log; quality class B tree (sound tree) –a live tree which would produce at least one 3 m long saw log; and quality class C tree (cull tree) - a live tree not qualified as class A or class B but would produce firewood only. Forest resources, particularly timber, face an uncertain future because of the high deforestation rate, rapid population growth, timber rights allocation system, forest fees, poor law enforcement, increasing demand for timber and energy, and sawmills being export-oriented (Oduro *et al*., 2014).

Generally, single trees in areas with lower density attain a larger diameter at breast height (DBH) and as a consequence, greater volume (Bembenek *et al*., 2014). Stem volume is an important parameter to estimate the monetary value of timber (Crecente-Campo *et al*., 2009). Categorization of TOFs based on diameter class and timber quality class is necessary for the valuation of the wood (Pompa-García, *et al*., 2009; Bembenek *et al*., 2014). The merchantable value of the wood depends on the species (Mejia *et al*., 2015). Merchantable value gives an idea about the economic importance of a species.

Organized tree planting was first started in Kathmandu valley in the Malla Era which was continued up to the Rana Era (Poudel, 2010). New species like *Araucaria araucana*, and other imported species from Europe along with pines were planted to beautify Kathmandu Valley urban areas and palaces. Later with the introduction of modern urban-environmental planning in the 1960s and 1970s, the Government renovated roads and trails throughout Kathmandu. Again in the 1980s, urban environmental planners introduced a three-line green belt. Trees were also planted along either side of other roads (Poudel, 2010), roadside gardens, and traffic islands (Baral and Kurmi, 2005). Many parks were also built during different historical eras. A botanical garden and zoo were also built. Thus, many native as well as exotic tree species were planted.

Kathmandu Valley is one of the fastest-growing urban agglomerations in South Asia (Muzzini & Aparicio, 2013). Mainly due to migration followed by rapid population, the urban core has expanded in the periphery (Chitrakar *et al*., 2014) and (Muzzini & Aparicio, 2013). Plant communities are sensitive to urban expansion and therefore may serve as indicators for human-induced land use change (Vakhlamova *et al*., 2014). The rural system usually is rich in natural vegetation (Xiao *et al.*, 2017) with more timber production whereas due to rapid urbanization, TOFs formations have increased with less timber production in the urban area. Thus tree species selection for afforestation in TOFs will help to minimize the demand-supply gap of timber (Shrivastav *et al*., 2012).

TOFs are little recognized in forest resources assessments, and has recently started receiving attention from the research community and the general public (Kleinn, 2000). Study of TOFs in terms of timber production would be important (Oli, 2002) because Nepal's annual import of wood and wooden materials exceeds NPR 6 billion (RSS, 2019). Though the Department of Forests Research and Survey (now the Forest Research and Training Center), the Government of Nepal has started the assessment of TOFs at the national level since FY 2004/05, (FAO, 2009), it is limited to only volume assessment by diameter class. The assessments of TOFs in terms of timber and firewood production along the urban-rural gradient are lacking. In this background, this study aims to analyze diameter class, quality class, wood production potential, and timber and firewood values of TOFs along the urban-rural gradient in the Kathmandu Valley of central Nepal.

5.2 Materials and methods

5.2.1 Study area

Same as in Chapter 2.

5.2.2 Methods

5.2.2.1 Site selection and sampling

Identification of sampling plots and sampling methods up to tree level characteristics were same as in Chapter 2. Tree quality class was also noted for individual trees. Methods for plant identification, vernacular names, scientific names were also same as in Chapter 2.

5.2.2.2 Data analysis

Species richness of the study area and across the strata were estimated for the area sampled at the study area and each stratum. Average species richness was calculated as the total number of species recorded per plot (Dorji *et al*., 2014).

5.2.2.2.1 Estimation of above-ground biomass of trees

The total above-ground tree biomass was estimated using an allometric equation developed by Petersson *et al.* (2012).

$$AGTB = 0.0509\ \rho\ D^2\ H$$

Where, AGTB = aboveground tree biomass (kg), ρ = wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), and H = tree height (m).
Sharma & Pukkala (1990) and Zanne *et al*. (2009) were used for wood-specific gravities of tree species. For the tree/shrub species for which wood-specific gravity data were not available, the arithmetic mean of all known tree/shrub species in the study area was used (Brown *et al*., 1989) (Appendix II).

5.2.2.2.2 Estimation of biomass of merchantable timber and firewood

Merchantable weights of the log of the quality class A tree and quality class B tree were calculated only for trees with DBH ≥30 cm as such trees are regarded as mature trees (DoF, 2004 and Brown *et al*., 2020). Our study followed the non-destructive method. So the biomass of merchantable timber of logs of class A tree and class B tree were estimated using the following allometric equations adapted from Petersson *et al.* (2012).

Merchantable weight of log of class A tree $AGTB = 0.0509 * \rho * D^2 * 6$ (kg)

Merchantable weight of log of class B tree $AGTB = 0.0509 * \rho * D^2 * 3$ (kg)

Where, AGTB = aboveground tree biomass (kg), ρ = wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), 6 and 3 are the lengths (m) of merchantable logs of class A and class B trees respectively.
The biomass of firewood was calculated for timber-yielding trees by subtracting the biomass of merchantable timber from the total AGTB of trees. The total AGTB of trees of class C was also accounted as firewood biomass. These biomasses were converted into

kg ha^{-1}. The merchantable biomass of merchantable timber of class A and class B trees were converted into ton ha^{-1}.

5.2.2.2.3 Economic valuation of merchantable timber and firewood

As the merchantable timber is sold in cu ft measurement, the biomass of merchantable timber of class A and class B trees in ton ha^{-1} were converted into volume (cubic feet) by multiplying with 40 (Wallis, 1970). The market value of merchantable timber of class A and B were calculated by multiplying the merchantable volumes by the per cu ft market price of timber. Unlike timber, firewood is sold in per kg measurement. So, the market value of firewood was calculated by multiplying the firewood biomass by the per kg market price of firewood. Retail market prices of class A, and class B logs and firewood of tree species were collected from the retail depots (n = 4) (Ahmed, 2008). The average market prices were used for valuation. For the tree species for which market prices were not available (both timber and firewood), the average values of market prices of all tree species were used (Bembenek *et al*., 2014). Market values of timber of class A and class B were added to that of firewood to get the total economic value of individual tree species. All these values were then summed up to get the total economic value of all tree species except the bamboo. As bamboo is sold as culms (Bhusal & Bashyal, 2020), their merchantable values were calculated by multiplying the density per hectare by the average market price. All these prices were then summed up to get the total merchantable value of wood in each stratum and the study sites. Economic values in NPR were converted into US$ by multiplying with 129.8 (1 US$ = 129.8 NPR, accessed on 11/7/2022)

5.2.2.2.4 Statistical analysis

First, the data were standardized. Standardized values are calculated by subtracting the sample mean of each variable from each observation and dividing this difference by the sample standard deviation (Gotelli & Ellison, 2013). Those values were then tested for normality. However, the data were not normal and their normality did not improve even after a transformation so the Kruskal-Wallis test and post-hoc Mann-Whitney test at $p \leq 0.05$ were used for comparison among groups. Paleontological Statistics Software Package for Education and Data Analysis (PAST) (V 4.09; Hammer *et al*., 2001) was used for analysis.

5.3 Results

5.3.1 Plant species diversity

A total of 150 plant species of the [trees (n=121) and shrubs (n=29)] belonging to 111 genera and 57 families were enumerated from the study area (Appendix I). Species numbers varied from 1-21. Species richness was 5.71 ha^{-1} with an average of 50.24±28.61 species ha^{-1}. The average species richness was found higher in the urban stratum than the suburban and the rural strata. However, the difference was not statistically significant (Table 29).

Table 29: Species richness of trees outside the forest along the urban-rural gradient in Kathmandu Valley, Nepal. The number of plots, species richness (range), species richness ha^{-1}, and average species richness (ha^{-1}) (±SD) in three strata are shown. Different superscript letters across column indicate statistical significance at $p<0.05$ (Kruskal-Wallis test followed by Mann-Whitney test).

Strata	Number of plots	Species richness (range)	Species richness (ha^{-1})	Average species richness (ha^{-1})
Urban	88	109 (1-21)	9.85	55.95±31.67^{a}
Suburban	73	89 (1-16)	9.7	46.31±26.99^{a}
Rural	48	85 (2-15)	14.09	45.74±23.35^{a}

5.3.2 Tree density, tree height, and stem DBH

The average tree density in the study area was 236.35±173.12 ha^{-1}. The maximum height of the tree was 31.50 m with an average of 6.83±3.77 m. Similarly, the maximum DBH of the stem was 203 cm with an average of 21.44±19.49 cm. The average tree density was higher in the suburban stratum (248.44±198.56 ha^{-1}) than in the urban (232.58±155.08 ha^{-1}) and rural (224.88±165.31 ha^{-1}) strata (Table 30). However, the difference was not statistically significant. The tallest tree (31.50 m) and widest tree (203 cm) were found in the urban stratum. The urban stratum was found to have statistically significant taller and wider trees than the suburban and rural strata (Table 30).

Table 30: Average tree density (±SD), maximum and average (±SD), tree height, and maximum and average (±SD) stem DBH of trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Different superscript letters across columns indicate statistical significance at $p<0.05$.

Strata	Average Tree Density (Number of stem ha^{-1})	Tree Height (m)		Stem DBH (cm)	
		Maximum	Average	Maximum	Average
Urban	232.58±155.08 ^{a}	31.5	7.64±4.63^{a}	203	22.80±19.85^{a}
Suburban	248.44±198.56 ^{a}	20.3	6.43±2.97^{bc}	157.3	20.36±16.80^{b}
Rural	224.88±165.31 ^{a}	23	5.92±2.68^{c}	187	20.62±22.59^{b}

5.3.3 Tree density by quality class and stem diameter class

The average density of merchantable trees of quality class A, quality class B, and quality class C in the study were 20.90±2.56 ha^{-1}, 13.09±1.53 ha$^{-1,}$ and 202.37±12.35 ha^{-1} respectively. The average density of merchantable trees of quality class A was found to be significantly higher ($p<0.05$) in the urban stratum than in the rural stratum but that did not differ significantly from that in the suburban stratum (Table 31). Moreover, the differences in average densities of merchantable trees of quality class B and C were not significant among the three strata ($p<0.05$).

Similarly, the average stem densities of diameter classes 5-9.90 cm, 10-19.90 cm, 20-29.90 cm, and ≥ 30 cm in the study area were found to be 79.51±7.42 ha^{-1}, 64.28±5.33 ha^{-1}, 34.94±2.53 ha^{-1} and 57.24±4.21 ha^{-1} respectively (Table 31). There were no significant differences in the average stem densities across different strata except for the diameter class 20-29.90 cm. Urban and suburban strata were found to have a significant stem density of diameter class 20-29.90 cm than the rural stratum (Table 31).

5.3.4 Volume and biomass of merchantable timber and firewood

Out of 53 tree species with merchantable timber recorded in the study area, 13 species could yield timber of quality class A, 13 could yield timber of quality class B, and 27 could yield timber of both quality class A and B (Appendix III).

The total volume of merchantable timber in the study area was 625.51 cu ft ha^{-1} with 549.33 cu ft ha^{-1} and 76.18 cu ft ha^{-1} as volumes of merchantable timber class A and class B. The total biomass of firewood was 50840.85 kg ha^{-1}. The volume of merchantable timber was highest in the urban stratum followed by rural and suburban strata while the biomass of firewood was highest in the urban stratum followed by suburban and rural strata (Table 32).

5.3.5 Market value of merchantable wood

The total market values were calculated based on the per unit market price of the timber and firewood in the study area (Appendix IV) (valued in September 2020). Based on the market values of individual tree species (Appendix V), the total market values of timber class A, timber class B, total timber, firewood, and total wood from the TOFs were found to be NPR. 746,613 (US$ 5,752), NPR. 96,358 (US$ 742), NPR. 842,971 (US$ 6,494), NPR. 516,612 (US$ 3,980) and NPR. 1362,880 (US$ 10,500) ha^{-1} (1 US$ = 129.8 NPR, accessed on 11/7/2022). The market value of total merchantable timber was highest in the rural stratum followed by urban and suburban strata while that of firewood was highest in the urban stratum followed by suburban and rural strata (Appendix VI, Appendix VII, Appendix VIII, and Table 33).

Cinnamomum camphora was the tree species with the highest market value of timber class A, timber class B, total timber, and total wood value ha^{-1} as (NPR. 229,851) (US$ 1,771), (NPR. 17,399) (US$ 134), (NPR. 247,250) (US$ 1,905) and (NPR. 2,96,101) (US$ 2,281) in the study area (Table 34). *Pinus roxburghii* was the tree species with the highest market value of firewood (NPR. 63,793) (US$ 491). The rural stratum had the highest merchantable values for timber class A in *C. camphora*, for total timber in *C. camphora*, for firewood in *Eucalyptus camaldulensis*, and total wood in *C. camphora* while the urban stratum had the highest merchantable value for timber class B in *C. camphora*.

Economically, *C. camphora* recorded from 86 plots and *P. roxburghii* recorded from 30 plots showed the highest merchantable timber and firewood values respectively in the study area. Thirtytwo timber class A and 49 timber class B logs of *C. camphora* were estimated from the study sites. *C. camphora* was the second highest expensive species, the retail market prices of which varied from NPR 2200 to 3200. *E. camaldulensis, Syzygium cumini,* and *Fraxinus floribunda* were other tree species with more economic valuations. Local merchantable market prices matter during valuation because they vary for a single species.

Table 31: Average densities (±SE) of trees by tree quality classes and stem diameter classes of trees outside the forest along the urban-rural gradient in Kathmandu Valley, Nepal. Different superscript letters across columns indicate statistical significance at $p<0.05$.

Strata	The average density of trees by quality class (ha^{-1})			Average stem density by diameter class (ha^{-1}) (cm)			
	A	**B**	**C**	**5-9.90**	**10-19.90**	**20-29.90**	**≥30**
Urban	28.20±6.57 ^{a}	15.37±3.40 ^{a}	189.02±23.20 ^{a}	66.26±9.99 ^{a}	68.97±7.56 ^{a}	37.06±3.82^{a}	60.29±6.41 ^{a}
Suburban	18.85±3.47 ^{ab}	11.77±2.56 ^{a}	217.83±24.26 ^{a}	87.83±13.99 ^{a}	61.35±5.95 ^{a}	40.10±7.36^{a}	59.17±9.15 ^{a}
Rural	10.61±2.77 ^{b}	10.94±2.12 ^{a}	203.35±17.44 ^{a}	92.80±16.03 ^{a}	60.16±4.94 ^{a}	23.20±4.20^{b}	48.72±12.35 ^{a}

Table 32: The volume of merchantable timber and biomass of firewood from trees outside the forest along the urban-rural gradient in Kathmandu Valley, Nepal. Volume ha^{-1} by quality class and total volume ha^{-1} of merchantable timber and total biomass ha^{-1} of firewood are shown.

Strata	Class A timber (cu ft ha^{-1})	Class B timber (cu ft ha^{-1})	Total timber (cu ft ha^{-1})	Firewood (kg ha^{-1})
Urban	537.08	84.88	621.96	55835.49
Suburban	250.04	47.31	297.35	39410.01
Rural	442.94	66.82	509.76	39032.12

Table 33: Market values (MV) of merchantable wood i.e., timber plus firewood from trees outside the forest along the urban-rural gradient in Kathmandu Valley, Nepal. Market values of timber of class A and B, total timber, firewood, and total wood in NPR and US$ are shown.

Strata	MV of timber class A (NPR ha^{-1})	US$	MV of timber class B (NPR ha^{-1})	US$	MV of total timber (NPR ha^{-1})	US$	MV of firewood (NPR ha^{-1})	US$	MV of total wood (NPR ha^{-1})	US$
Urban	698,567	5,382	108,255	834	806,821	6,216	488,709	3,765	1,295,531	9,981
Suburban	383,485	2,954	60,759	468	444,244	3,423	444,104	3,421	888,828	6,848
Rural	789,871	6,085	80,539	620	870,410	6,706	380,303	2,930	1,250,713	9,636

(MV valued in September 2020), (1 US$ = 129.8 NPR, accessed on 11/7/2022)

Table 34: Tree species and their market values (MV) of timber class A, timber class B, total timber, firewood, and the total wood in different strata of the study area.

Strata	Species	MV of timber class A (NPR ha^{-1})	US$	Species	MV of timber class B (NPR ha^{-1})	US$	Species	MV of total Timber (NPR ha^{-1})	US$	Species	MV of firew Ood (NPR ha^{-1})	US$	Species	MV of total wood (NPR ha^{-1})	US$
Urban	*Cinnamomum camphora*	218,142	1,681	*Cinnamomum camphora*	31,077	239	*Cinnamomum camphora*	249,219	1,920	*Pinus roxburghii*	86,736	668	*Cinnamomum camphora*	315,156	2,428
Suburban	*Eucalyptus camaldulensis*	116,498	898	*Syzigium cumini*	16,069	124	*Eucalyptus camaldulensis*	120,125	925	*Pinus roxburghii*	91,760	707	*Syzigium cumini*	175,826	1,355
Rural	*Cinnamomum camphora*	530,006	4,083	*Fraxinus floribunda*	15,196	117	*Cinnamomum camphora*	543,055	4,184	*Eucalyptus camaldulensis*	92,461	712	*Cinnamomum camphora*	591,656	4,558

(MV valued in September 2020), (1 US$ = 129.8 NPR, accessed on 11/7/2022)

5.4 Discussion

A total of 150 plant species were recorded from the sampled study area. Vakhlamova *et al*. (2014) found slightly high species richness (160) in the urban–the rural gradient in Kazakhstan. It might be due to the enumeration of all vascular plants regardless of DBH in the study. Moreover, Thompson (2010) found comparatively less species diversity (22) from Khartoum, Sudan. It is possibly due to the enumeration of only the living fences in the urban and suburban gardens where homogeneity of species occurs. Species richness in terms of stratum area (ha^{-1}) was higher in the rural stratum than in the urban and suburban strata (Table 30). Vakhlamova *et al*. (2014) also found an increasing trend of species richness from urban to rural in urban–rural gradient in Kazakhstan, Western Siberia. This pattern can be explained by the fact that plant life forms and evolutionary strategies do not follow a particular urban-rural gradient, but rather are affected by varied habitat and landscape features. In addition, reduced suitable habitats for plants in densely built-up urban areas and excessive trampling of vegetated patches might cause a decrease in plant diversity (Aronson *et al*., 2014). Average species richness (ha^{-1}) was higher in the urban stratum than in suburban and rural strata which is due to planted types of trees in the urban stratum while the majority of them were natural woodlots in the remaining strata.

Tree density in the present study area was found higher than that in TOFs in Morang (15 ha^{-1}) (DFRS, 2007) and Nawalparasi (10 ha^{-1}) districts (Kharal *et al*., 2008) which might be due to the dominance of agricultural lands and less tree plantation culture in Terai area. Moreover, trees with DBH > 10 cm were presented in the results in those districts. The average tree density was found more in the suburban stratum than in urban and rural strata which is due to the abundance of trees with 20-29.9 cm stem diameter class indicating more branched trees here.

The higher average tree density in the urban stratum than in rural in this study (Table 5.3) showed similar patterns in Morang and Nawalparasi districts (DFRS, 2007; Kharal *et al*., 2008). This pattern could be due to plantation drives (also including exotic species) during the Panchayat regime in the urban areas in Kathmandu Valley and major other urban areas (Goutam, 2018). Moreover, rural people cut down trees for domestic use. The average tree heights and average DBH also followed the same distribution pattern (DFRS, 2007; Kharal *et al*., 2008).

The average density of tree quality class A and B was found more in the urban stratum than in the suburban and rural strata whereas that of tree quality class C was found more in the rural stratum than in the suburban and urban strata (Table 32). This is supported by the occurrence of more average stem density and distribution of mature trees (≥30) in the urban stratum. This is due to more abundance of such mature trees (for example *Eucalyptus camaldulensis, Ficus elastica, Jacaranda mimosifolia,* etc.) in the parks, roads, rivers, and streamlines, etc. whereas due to less dominance of such sized trees, rural stratum had less average tree density with the dominance of smaller stem diameter class. Furthermore, both the tallest tree and widest tree were also recorded in the urban stratum.

Out of four stem diameter classes, the dominance of the smaller diameter class (5-9.90 cm and 10-19.90 cm) in the urban stratum in the study area (Table 32) is similar to Morgenroth *et al*. (2020) reported in America's urban forests as > 40% of trees in the smallest DBH class (< 15 cm) which could be attributed to the preference for smaller ornamental trees as Bottlebrush, Albizia, Junipers, etc. in urban areas or a recent increase in tree planting efforts. A greater proportion of stem diameter classes of 10-19.9 cm and ≥ 30 cm in urban stratum were also the same as Morgenroth *et al*. (2020) found the dominance of 16–45 cm DBH class in urban forests. This may be due to the existence of youthful trees. As regards the stem densities of diameter classes 5-9.90 cm, 10-19.90 cm, 20-29.90 cm, and ≥ 30 cm in Kathmandu Valley, values are higher than those reported from Morang (DFRS, 2007) and Nawalparasi (Kharal *et al*., 2008); that could be attributed to less planted trees in both Morang district and Nawalparasi district. Further, stem density of lower diameter class (5-9.90 cm) was higher in the rural stratum than that in suburban and urban strata whereas stem densities of higher diameters were higher in urban and suburban strata except for trees of diameter 20-29.9 cm which showed uneven distribution. This result is consistent with the findings reported from Morang district (DFRS, 2007), but different from that reported from Nawalparasi district (Kharal *et al*., 2008). This could be due to more naturally regenerated trees in the rural stratum in both Morang and the study area. Also, tree plantation drive earlier during the Rana regime and Panchayat regime would have contributed to this pattern of tree size class distribution (Goutam, 2018).

TOFs are important in terms of wood production. DFRS (2015), based on FAO recommendation, has stated that 13.29% of middle mountain forests have the potential for timber production. This study shows a slightly higher value (14.38%) of timber production by TOFs. Similar results are found in India (FSI, 2011; Ghosh & Sinha, 2018) as well as in Kerala, India (Krishnankutty *et al*., 2008). But Yadav *et al*. (2020) reported a higher percentage of timber production (25.17%) from TOFs in Dhangadhi Municipality, Siraha district, Nepal which is due to more distribution of planted tree species with wider DBH there.

In a study by Bembenek *et al*. (2014), high mean tree height, mean DBH and high mean volume of merchantable timber with a low mean tree density of Scots pine were reported. The higher volumes of merchantable timbers of class A and class B in the urban stratum than in rural and suburban strata in the study area could be due to the distribution of more mature and taller trees. It might be due to the conservation of the old trees in the parks, roadsides, river lines, pond lines, etc. Similarly, lower volumes of merchantable timbers of class A and class B in the rural stratum might be due to lesser tree density as well as less dominance of stem density of ≥ 30 diameter class.

5.5 Conclusions

Urban TOFs are important in terms of species diversity whereas suburban TOFs are richer in terms of density. Due to the presence of large-sized tree species planted during the Rana regime, urban TOFs have taller and wider trees. Due to more tree density of timber class A and class B in the urban stratum, volumes of total merchantable timber along with timber class A and class B and biomass of merchantable firewood were also found higher here. Rural TOFs are economically more important. Due to high market prices of the wood of tree species recorded in the rural stratum, the market value of timber class A and total timber was found higher in the rural stratum than the others. Urban TOFs are also economically important because it showed high market value for B-class timber, firewood, and total wood. In terms of TOFs species, *C. camphora* and *P. roxburghii* were found to be economically more important as they showed the highest merchantable timber and firewood values. People should be encouraged to afforestation in TOFs areas with these species which offers an opportunity for timber availability and could help in local livelihood. On the other hand, the import of wood and wooden materials could be minimized as well as urban greenery would be enhanced.

CHAPTER 6

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

Trees Outside Forests **(**TOFs) are a vegetation type of new concept worldwide. It might be natural (natural woodlots, forest fragments with more endemic plant species) or artificial (planted ones with more exotic species). Due to migration and rapid urbanization, grey infrastructure is increasing and green infrastructure is decreasing. In such conditions, TOFs in the form of urban forestry is getting more attention worldwide.

TOFs as green infrastructure not only support biodiversity and act as a carbon sink, but also benefit other ecosystem services. These play critical roles in lessening the pressure on forest ecosystem services, and also serve as Tree-related microhabitats **(**TreMs). TOFs are equally important as source of wood including both timber and firewood.

The study has attempted to analyze the community structure and carbon stock (phytomass carbon and soil organic carbon), the ecosystem services they provide (habitat service), and the economic valuation (timber and firewood) of the TOFs of Kathmandu Valley in the central mid-hill physiographic region of Nepal. The overall objective of the proposed research was to assess the status of TOFs in the study area by assessing the diversity of trees and shrubs. Specifically, this study assesses the biomass and soil carbon, evaluates the ecosystem services (habitat) provided by TOFs and assesses the economic value (timber and firewood) of TOFs.

In this study, a two-phase sampling method was adopted, the first was the Google interpretation (aerial photographs) to locate the TOFs distribution sites, and the second was the data collection. Stratified random sampling techniques were adopted for data collection. Circular sampling plots of 20 m radii were used to collect data for tree-level characteristics and soil samples. Tree level characteristics such as number, DBH and height of the plants along with the tree quality class were collected from each circular plot. Soil samples were collected from five soil pits, four being in each cardinal direction and one being at the center of each sample plot. TOFs plant density, species richness, species similarity index as well as family similarity index were estimated. Shannon-Weiner diversity index, evenness, maturity index, Menhinick’s species richness index were also determined. Phytosociological parameters such as species importance value, family importance value were calculated. Phytomass carbon of plant species were estimated following standard procedure. Soil carbon content was estimated by using the Walkley-Black (1934) method and SOC was calculated following Pearson *et al*. (2007). Tree related microhabitats along with inhabiting species were also recorded. Merchantable volumes of Quality Class A trees, Quality Class B trees were estimated for the valuation of merchantable timber using the standard formulae. Similarly, merchantable weights of plant species with firewood were estimated for the valuation of merchantable firewood.

In total 209 plots [urban (88), suburban (73), and rural (48) strata] were surveyed in the study area. The findings of this thesis are summarized in four sections. The first section (6.1.1) draws on chapter 2 and deals with the phytosociological assessment of TOFs along urban–rural gradient in Katmandu Valley. The second section (6.1.2) draws on chapter 3 and deals with the assessment of tree species richness, phytomass carbon stock and soil organic carbon in TOFs along the urban-rural gradient in TOFs of Kathmandu Valley. The third section (6.1.3) draws on chapter 4 and deals with TOFs as the TreMs along the urban-rural gradient in Kathmandu Valley. The forth section (6.1.4) draws on chapter 5 and deals with the valuation of timber and firewood of trees outside the forest along the urban–rural gradient in Kathmandu Valley.

6.1.1 Diversity and phytosociological assessment of trees outside forests along urban–rural gradient in Katmandu Valley, Nepal

Tree level characteristics were recorded in three strata in the Kathmandu Valley. TOFs plant density, species richness, species similarity index as well as family similarity index were estimated. Shannon-Weiner diversity index, evenness, maturity index, Menhinick's species richness index were also determined. Phytosociological parameters such as species importance value, family importance value were calculated. This study showed the following results.

The average tree density was 236.35 ha^{-1} in the study area. It was higher in the suburban stratum than in the urban and the rural strata. The average species richness in the study area was 50.24 ha^{-1}. It was higher in the urban stratum than in suburban and rural strata. Native species were found in higher number in the study area. Of the tree strata studied, the suburban stratum was found higher in native species numbers than those in the urban and rural strata. On the basis of similarity index, 74.73% of families and 66.33% of tree species were found to be similar between urban and suburban strata. 84.71% of families and 66.29% of tree species were found to be similar between suburban and rural strata. Similarly, 82.61% of families and 62.89% of tree species were found to be similar between urban and rural strata. Likewise, 33 families and 50 species were found common in all three strata. Average species richness was higher in urban stratum (55.95) than in the suburban (46.31) and rural (45.74) strata. Based on the average Shannon Weiner diversity index, the urban stratum was found more diverse than the rural and suburban. Trees were found to be more evenly distributed in the urban stratum than the rural and the suburban strata. The TOFs of the rural stratum was found to be more mature than the urban and suburban. Based on the average Menhinick's species richness index, rural stratum was richer than the urban and rural. The most important tree species was *Cinnamomum camphora* (IVI = 32.82) in the urban stratum while it was *Pinus roxburghii* (IVI = 27.83) in suburban and *Bambusa nepalensis* (IVI = 30.97) in rural strata respectively. Similarly, the most important family was Lauraceae (FIV = 3.89) in the urban stratum while it was Myrtaceae (FIV = 2.97) in suburban and Gramineae (FIV = 2.47) in the rural strata respectively.

6.1.2 Phytomass carbon stock in TOFs and SOC

Tree level characteristics were recorded in three strata in the Kathmandu Valley. Phytomass carbon of TOFs plant species were estimated following standard procedure. Soil carbon content was estimated by using the Walkley-Black (1934) method and SOC was calculated following Pearson *et al*. (2007). This study showed the following results.

The urban stratum had the taller and wider plants than the suburban and the rural strata. Likewise, the average phytomass C stock was higher in the urban stratum than in the rural and the suburban strata. Average SOC was higher in the rural stratum than in the suburban and the urban. Both average phytomass C stock and average SOC were almost equal in the urban stratum. Phytomass carbon (t ha^{-1}) and species richness showed a significant positive linear relationship in the study area. The average phytomass carbon stock between the native species and the exotic species did not vary significantly in the study area. It varied significantly between the native species and the exotic species only in the urban stratum but not in suburban and rural strata.

6.1.3 Ecosystem services of TOFs as TreMs

Plants of TOFs also serve as tree related microhabitats. Tree species serving as TreMs along with inhabiting species were also recorded. Cavities, nests (birds, ants), beehives and sap runs if present were also recording This study showed the following results.

A total of 4 forms, 5 groups, and 14 types microhabitats were recorded in the study area. The average number of trees with cavities as TreMs was found more in the urban stratum than in the rural and the suburban strata. The average number of trees with annual and perennial polypores of fungi as TreMs was found higher in the urban stratum than in the suburban. They were not recorded in the rural stratum during this study. The average number of trees with moss was higher in the rural stratum than urban and suburban. The average number of trees with lichens was found more in the suburban stratum than in rural and urban. The average number of trees with ivy was more in the rural stratum than in the urban and suburban. The average number of trees with ferns was also more in the rural stratum than in the urban and suburban. Mistletoe was recorded only in the urban stratum. The average number of trees with orchids was more in the rural stratum than in the suburban and urban. But the average number of trees with other phanerogams was higher in the urban stratum than in the suburban and rural. Similarly, the average number of trees with vertebrate nests was found more in the suburban stratum than in the urban and rural but the average number of trees with invertebrate nests was found more in the urban stratum than in suburban. Such trees were not recorded in the rural stratum. The average number of trees with sap run was more in the suburban stratum than in the urban. Such trees were not recorded in the rural stratum.

6.1.4 Economic valuation of timber and firewood of TOFs

Plants of TOFs are important as timber and firewood. Diameter class and tree quality class are tools to estimate timber in a tree. Tree level characteristics were recorded in three strata in the Kathmandu Valley. Quality classes of individual recorded plant was also noted. Merchantable volumes of Quality Class A trees, Quality Class B trees were estimated for the valuation of merchantable timber using the standard formulae. Similarly, merchantable weights of plant species with firewood were estimated for the valuation of merchantable firewood. This study showed the following results.

Average stem density by diameter class 5-9.90 cm was higher in the rural stratum than in the suburban and urban. Average stem density by diameter class 10-19.90 cm was higher in the urban stratum than in the suburban and rural. Average stem density by diameter class 20-29.90 cm was higher in the suburban stratum than in urban and rural. Similarly, average stem density by diameter class ≥30 cm was higher in the urban stratum than in the suburban and rural.

In the case of tree quality class, the average density of trees by quality class A was higher in The volume of merchantable Class A timber was higher in the urban stratum than in rural and suburban. The volume of merchantable Class B timber was also higher in the urban stratum than in rural and suburban. The volume of merchantable firewood was higher in the urban stratum than in the suburban and rural.

Based on the market value of merchantable wood, the rural stratum had the highest market value for timber class A than the urban and suburban but the urban stratum had highest market value for timber class B than rural and suburban. Similarly, the urban stratum had the highest market value for firewood than the suburban and rural. So urban stratum had the highest market value for total wood than rural and suburban strata.

Cinnamomum camphora was the tree species found with the highest market value of timber class A, and timber class B whereas *Pinus roxburghii* was the tree species with the highest market value of firewood in the study area. The rural stratum had the highest merchantable values for timber class A in *C. camphora*, for total timber in *C. camphora*, for firewood in *Eucalyptus camaldulensis*, and total wood in *C. camphora* while the urban stratum had the highest merchantable value for timber class B in *C. camphora*.

6.2 Conclusions

With rapid urbanization, urban and suburban areas have been increasing in Kathmandu Valley leading to the disturbance in natural vegetation and fragmentation of lands resulting in more formations of TOFs. The study reported 150 species and 111 genera belonging to 57 plant families in the TOFs of Kathmandu Valley. Tree density as well as species richness in TOFs in the study area indicated that they are important components of greenery and play a significant role in biodiversity conservation in the study area even though they are less rich than that in the Middle Mountain Forests of Nepal. Suburban stratum in the Kathmandu valley was found more evenly distributed with trees and the diversity was also higher there. Urbanization is said to be harmful to the diversity of native plant species. But due to plantation culture, native species were found in higher number in the urban stratum. Urban greenery is diminishing nowadays, urban TOFs are very important besides the biodiversity and conservation of native species.

Urban TOFs in Kathmandu Valley appear to be of great importance for carbon storage due to the higher average height and DBH of trees in the study area. In contrast, rural TOFs are important as they stored the highest average SOC than the TOFs of suburban and urban strata. The study indicated that even under suburban environment the soil has higher carbon stock. It highlights the necessity to implement conservation-based production systems with the inclusion of woody perennials. Although both native and exotic plant species contribute in carbon storage, larger sized exotic tree species such as *Araucaria* spp. are important for more carbon storage.

This study provides fundamental information about the importance of both TOFs and TreMs in terms of biodiversity and its conservation in Kathmandu Valley, Nepal. Lichens are the dominating habitant on TOFs, followed by mosses and bird nests. Habitat types are species-specific. *Cinnamomum camphora* as the individual tree of the rural stratum served maximum habitat types (6). Habitat types might or might not be dependent on the DBH of the tree. Generally, co-occurrence of microhabitat is more common on trees with greater DBH. Microhabitats are also strata-specific because maximum habitat types (7) were found in urban and rural strata. Both urban and rural TOFs contribute significantly to biodiversity conservation because maximum habitat types (7) were found in both strata.

Urban TOFs are important in terms of species diversity whereas suburban TOFs are richer in terms of density. Due to the presence of large-sized tree species planted during the Rana regime, urban TOFs have taller and wider trees. Due to more tree density of timber class A and class B in the urban stratum, volumes of total merchantable timber along with timber class A and class B and biomass of merchantable firewood were also found higher here. Rural TOFs are economically more important. Due to high market prices of the wood of tree species recorded in the rural stratum, the market value of timber class A and total timber was found higher in the rural stratum than the others. Urban TOFs are also economically important because that showed high market value for B-class timber, firewood, and total wood. In terms of TOFs species, *C. camphora* and *P. roxburghii* were found to be economically more important as they showed the highest merchantable timber and firewood values.

C. camphora with multiple uses being the dominant plant species in the urban stratum, more benefits should be taken from such plants. People should be encouraged for tree plantation in TOFs areas with these species which offers the opportunity for timber availability and could help in local livelihoods. On the other hand, the import of wood and wooden materials could be minimized as well as urban greenery would also be enhanced. The database of such assessments provides opportunities for framing significant policy or management decisions about the relationship between carbon storage and species diversity.

6.3 Recommendations for further research and management

This research has identified *Grevillea robusta* and *Cinnamomum camphora* as the important tree species with the highest IVI values in the study area. Such tree species are found in roadside plantations, parks, home gardens, Government offices, academic institutions. Presence of these tree species serves in urban greenery and ornamental purpose. Therefore, more plantations of these species by people and the authorities in TOFs forms are highly recommended.

This research further showed that *C. camphora*, *G. robusta* and *Pinus roxburghii* are the highest carbon storing tree species. May be more silvicultural practices on *C. camphora*, *G. robusta* and *P. roxburghii* and their timely thinning, pruning may enhance the air quality and manage carbon in the atmosphere.

Among the tree species found in the study area, *C. camphora* was found to serve various kinds of microhabitat services especially in the rural stratum. It is, therefore, advisable to increase the number of this species in plantation drives for biodiversity conservation.

This research has explored the economical aspect of TOFs. *C. camphora* and *P. roxburghii* showed the highest merchantable timber and firewood values in the study area. Maximum number of timber class A and timber class B logs of *C. camphora* were recorded from the study sites. *C. camphora* was found to be the expensive tree species in our study. So to minimize the import of wood and wooden materials, more plantations of this tree species in TOFs forms should be encouraged.

TOFs are kept under forestry and not much research has been done in this field. As ecosystem services are emerging topic of forestry nowadays, further research on TOFs should be encouraged in order to explore various aspects of forest services from TOFs.

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APPENDICES

Appendix I: Plant species recorded in TOFs in the study area with vernacular names, English names, families, growth forms and origins. G.F.* – Growth Form (T – Tree, S - Shrub), O** – Origin (Kew Science. Plants of the World Online (N-Native, E-Exotic).

S.N.	Scientific name	Vernacular name	English name	G.F.* /O**	Family
1	*Acacia nilotica* (L.) Willd. ex Del.	Babool	Gum arabic tree	T/N	Leguminosae
2	*Acer oblongum* Wall. ex DC.	Phirphire	Himalayan maple	T/N	Sapindaceae
3	*Agave cantula* Roxb.	Ketuke	Century plant	S/E	Agavaceae
4	*Alangium chinense* (Lour.) Harms	Baman patti	Chinese alangium	T/N	Alangiaceae
5	*Albizia julibrissin* Durazz.	Rato siris	Mimosa tree	T/N	Leguminosae
6	*Albizia procera* (Roxb.) Benth.	Seto siris	White siris tree	T/N	Leguminosae
7	*Alnus nepalensis* D. Don	Uttis	Alder	T/N	Betulaceae
8	*Alstonia neriifolia* D. Don			T/N	Apocynaceae
9	*Alstonia scholaris* (L.) R. Br.	Chatiwan	Devil's tree	T/N	Apocynaceae
10	*Anthocephalus chinensis* (Lam.) A. Rich. ex Walp.	Kadamgachi	Kadam	T/E	Rubiaceae
11	*Araucaria bidwillii* Hook.	Dhengre sallo	Monkey puzzle	T/E	Araucariaceae

12	*Araucaria columnaris* J. R. Forst & Hook.		Coral reef araucaria	T/E	Araucariaceae
13	*Araucaria heterophylla* (Salisb.) Franco		Living Christmas tree	T/E	Araucariaceae
14	*Areca catechu* L.	Bhale supari	Betel nut	T/E	Palmae
15	*Artocarpus integra* (Thumb.) Merr.	Rookh katahar	Jack fruit	T/E	Moraceae
16	*Azadirachta indica* A. Juss.	Neem	Neem tree	T/E	Meliaceae
17	*Bambusa nepalensis* Stapleton	Bansa	Bamboo	T/N	Gramineae
18	*Bauhinia variegata* L.	Koiralo	Purple orchid tree	T/N	Leguminosae
19	*Berberis asiatica* Roxb. ex DC.	Chutro	Barberry	S/N	Berberidaceae
20	*Borassus flabellifer* L.	Taad	Toddy palm	T/E	Palmae
21	*Bougainvillea glabra* Choisy	Kagaj phool	Paper flower	S/E	Nyctaginaceae
22	*Brugmansia arborea* Pers.	Dhaturo	Angel's trumplet	S/E	Solanaceae
23	*Buchanania latifolia* Roxb.	Chiraungi	Cuddaph almond	T/N	Anacardiaceae
24	*Buddleja asiatica* Lour.	Bhimsenpati	Butterfly bush	S/N	Loganiaceae
25	*Burretiokentia vieillardii* Pic. Serm.	Taad	Tiger palm	T/E	Palmae
26	*Callistemon citrinus* (Curtis) Skeels	Kalki phool	Bottle brush	T/E	Myrtaceae
27	*Camellia japonica* L.	Chinia guransa	Garden camellia	S/E	Theaceae

28	*Carica papaya* L.	Mewa	Papaya	T/E	Caricaceae
29	*Carya illinoensis* (Wangenheim) K. Koch	Picanut	Pecan	T/E	Juglandaceae
30	*Caryota urens* L.	Jagar	Fish- tail palm	T/E	Palmae
31	*Cassia fistula* L.	Raj brichya	Cassia pods	T/N	Leguminosae
32	*Cassia mimosaides* L.	Amala jhar	Tooth cup	S/N	Leguminosae
33	*Casuarina equisetifolia* L.	Jangali jhyau	Whistling pine	T/E	Casuarinaceae
34	*Cedrus deodara* (Roxb. ex D. Don) G. Don	Devdaru	Deodar	T/N	Pinaceae
35	*Celtis australis* L.	Khari	Europian nettle tree	T/E	Ulmaceae
36	*Cestrum nocturnum* L.	Rat ki rani	Night jasmine	S/E	Solanaceae
37	*Choerospondias axillaris* (Roxb.) B. L. Burtt & A.W. Hill	Lapsi	Nepali hog plum	T/N	Anacardiaceae
38	*Cinnamomum camphora* (L.) J. Presl	Kapoor	Camphor	T/E	Lauraceae
39	*Cinnamomum tamala* (Buch-Ham) Nees & Eberm.	Tejpatta	Cinnamon leaf	T/N	Lauraceae
40	*Citrus aurantifolia* (Christm) Swingle	Kagati	Lemon	T/E	Rutaceae
41	*Citrus jambhiri* Lush.	Jyamir	Florida lemon	T/E	Rutaceae
42	*Citrus limon* (L.) Burn. F.	Nibuwa	Lime	T/E	Rutaceae
43	*Citrus maxima* (Burm.) Herr.	Bhogate	Pummelo	T/E	Rutaceae

44	*Citrus reticulata* Blanco.	Suntala	Mandarin orange	T/E	Rutaceae
45	*Cotinus coggygria* (Scop.)	Rato peepal	Smoke bush	S/N	Anacardiaceae
46	*Croton roxburghii* Balakrishnan	Ach	Croton	T/E	Euphorbeaceae
47	*Cycus pectinata* Buch.-Ham.	Kalbal	Cycas	T/N	Cycadaceae
48	*Cyphomandra betaceae* (Cav.) Sendt	Tyamter	Tree tomato	S/E	Solanaceae
49	*Dalbergia sissoo* Roxb.	Sisau	Indian rosewood	T/N	Leguminoceae
50	*Diospyros kaki* Thunb.	Haluwabed	Persimon	T/E	Ebenaceae
51	*Diploknema butyracea* (Roxb.) Lam.	Chiuri	Butter fruit	T/N	Sapotaceae
52	*Duranta erecta* L.	Nil kanda	Golden dewdrops	S/E	Verbenaceae
53	*Elaeocarpus sphaericus* (Gaertn.) K. Schum.	Rudrakshya	Utrasum bead tree	T/N	Elaeocarpaceae
54	*Eriobotrya japonica* (Thumb.) Lindl.	Laukat	Loquat	T/E	Rosaceae
55	*Erythrina arborescens* Roxb.	Theki kath	Himlayan coral bean	T/N	Leguminosae
56	*Erythrina stricta* Roxb.	Phaledo	Indian coral tree	T/N	Leguminosae
57	*Eucalyptus camaldulensis* Dehn.	Masala	River red gum	T/E	Myrtaceae
58	*Euphorbia pulcherrima* Willd. Ex Klotzsch	Lalupate	Poinsettia	S/E	Euphorbeaceae
59	*Ficus auriculata* Lour.	Timilo	Roxburgh fig	T/N	Moracea

60	*Ficus benghalensis* L.	Bar	Banyan fig	T/N	Moraceae
61	*Ficus benjamina* L.	Sami	Weeping fig	T/N	Moraceae
62	*Ficus elastica* Roxb.	Rubber plant	Rubber plant	T/N	Moraceae
63	*Ficus lacor* Buch.-Ham.	Kabhro	Java fig	T/N	Moraceae
64	*Ficus neriifolia* Sm.	Dudhilo	Willow leaf fig	T/N	Moraceae
65	*Ficus religiosa* L.	Pipal	Sacred fig	T/N	Moraceae
66	*Ficus semicordata* Buch- Ham ex Sm.	Khanayo	Drooping fig	T/N	Moraceae
67	*Fraxinus floribunda* Wall.	Lankure	Ash	T/N	Oleaceae
68	*Ginkgo biloba* L.	Bal kumari	Maidenhair tree	T/N	Ginkgoiaceae
69	*Gossypium arborium* L.	Kapas	Cotton plant	S/E	Malvaceae
70	*Grevillea robusta* A. Cunn. ex R. Br.	Kagiyo	Silky oak	T/E	Proteaceae
71	*Hibiscus brackenridgei* A. Gray		Rose mallow	S/E	Malvaceae
72	*Hibiscus rosa-sinensis* L.	Ghanti phool	China rose	S/E	Malvaceae
73	*Homalium napaulense* (DC.) Benth.	Falame kanda		T/N	Flacourtiaceae
74	*Ilex excelsa* (Wall.) Hook. Fil.	Pwanle		T/N	Aquifoliaceae
75	*Jacaranda mimosifolia* D. Don	Nilo phool	Jacaranda	T/E	Bignoniaceae

76	*Jasminum mesnyi* Hance	Double jai	Primrose jasmine	S/E	Oleaceae
77	*Juglans nigra* L.	Hade okhar	Black walnut	T/E	Juglandaceae
78	*Juglans regia* L.	Dante okhar	English walnut	T/E	Juglandaceae
79	*Juniperus chinensis* L.	Dhupi	Chinese juniper	S/E	Cupressaceae
80	*Juniperus communis* L.	Dhupi	Pencil cedar	S/N	Cupressaceae
81	*Juniperus indica* Bertol.	Dhupi	Black juniper	S/N	Cupressaceae
82	*Juniperus recurva* Buch.-Ham. ex D. Don	Dhupi	Himalayan juniper	T/N	Cupressaceae
83	*Lagerstroemia indica* L.	Asare phool	Crape myrtle	T/N	Lythraceae
84	*Lagerstroemia parviflora* Roxb.	Bot dhairo	Crepe flower	T/N	Lythraceae
85	*Lagerstroemia reginae* Roxb.	Thulo asare	Queen's crape myrtle	S/E	Lythraceae
86	*Leucaena leucocephala* (Lam.) De Wit	Epil	Ipil ipil	T/E	Leguminoseae
87	*Ligustrum confusum* Decne.	Kanike rookh	Privet	T/N	Oleaceae
88	*Lindera pulcherrima* (Nees) Benth. ex Hook. F.	Shyal phusre	Wild privet	T/N	Lauraceae
89	*Litchi chinensis* Sonner	Lichi	Lychee	T/E	Santalaceae
90	*Litsea monopetala* (Roxb.) Pers.	Kutmiro	Many-flowered litsea	T/N	Lauraceae
91	*Macadamia integrifolia* Maiden & Betche		Queensland nut	T/E	Proteaceae

92	*Madhuca longofolia* (Koeing)	Chiuri	Macbride	T/N	Sapotaceae
93	*Magnolia soulangeana* Soul.	Neel kamal	Saucer magnolia	T/E	Magnoliaceae
94	*Mahonia nepaulensis* DC.	Jamanemandro	Mahonia	T/N	Berberidaceae
95	*Malvaviscus arboreus* Cav.	Khursani phool	Turkcap	S/E	Malvaceae
96	*Mangifera indica* L.	Aap	Mango	T/E	Anacardiaceae
97	*Manglietia insignis* (Wall.) Blume	Rookh kamal		T/N	Magnoliaceae
98	*Melia azedarach* L.	Bakaino	China berry	T/N	Meliaceae
99	*Michelia champaka* L.	Champ	Champaca	T/E	Magnoliaceae
100	*Michelia fuscata* Bl.	Kankakchampa	Banana shrub	S/E	Magnoliaceae
101	*Miliusa velutina* (Dunal) Hook. f. & Thombs	Kali kath	Velveti miliusa	T/N	Annonaceae
102	*Morus alba L.*	Kimbu	Common mulberry	T/E	Moraceae
103	*Murraya koenigii* (L.) Sprengel	Kadi patta	Curry tree	T/N	Rutaceae
104	*Musa paradisiaca* L.	Kera	Banana	S/E	Musaceae
105	*Myrica esculenta* Buch-Ham. ex D. Don	Kafal	Box myrtale	T/N	Myricaceae
106	*Myrsine capitellata* Wall.	Seti kath		T/N	Myrsinaceae
107	*Nerium indicum* Miller	Karbir	Indian oleander	T/N	Apocynaceae

108	*Nerium oleander* variegatum	Kannel	Kaner	T/E	Apocynaceae
109	*Nyctanthes arbor-tristis* L.	Parijat	Coral jasmine	T/N	Oleaceae
110	*Persea americana* Mill.	Ghiu phal	Avocado	T/E	Lauraceae
111	*Persea duthiei* (King ex Hook. F.) Kosterm.	Kaulo	Duthiei bay tree	T/N	Lauraceae
112	*Phoenix humilis* Royle.	Khajur	Dwarf date palm	T/N	Palmae
113	*Phoenix sylvestris* Roxb.	Taadi	Wild date palm	T/N	Palmae
114	*Phyllanths emblica* L.	Amala	Emblic	T/E	Euphorbeaceae
115	*Pinus roxburghii* Sarg.	Khote salla	Chir pine	T/N	Pinaceae
116	*Platanus orientalis* L.	Chinar	Oriental plane	T/E	Platanaceae
117	*Podocarpus neriifolius* D. Don	Gunsi	Oleander Podocarp	T/N	Podocarpaceae
118	*Populus jacquemontiana* Dode.	Lahare pipal	Poplar	T/N	Salicaceae
119	*Prunus avium* L.	Cherry	Sweet cherry	T/E	Rosaceae
120	*Prunus cerasoides* D. Don	Paiyun	Himalayan cherry	T/N	Rosaceae
121	*Prunus domestica* L.	Aaloo bokhada	Europian plum	S/E	Rosaceae
122	*Prunus persica* (L.) Batsch	Aaroo	Peach	T/E	Rosaceae
123	*Psidium guajava* L.	Amba	Guava	T/E	Myrtaceae

124	*Punica granatum* L.	Anar	Pomegranate	T/E	Punicaceae
125	*Pyrus communis* L.	Naspati	Europian pear	T/E	Rosaceae
126	*Pyrus crenata* Buch.- Ham. ex D. Don.	Naspati	Wild pear	T/N	Rosaceae
127	*Pyrus malus* L.	Syau	Apple	T/E	Rosaceae
128	*Pyrus pashia* Buch.-Ham. ex D. Don.	Mayal	Wild Himalayan pear	T/N	Rosaceae
129	*Pyrus pyrifolia* (Burn.) Nak.	Naspati	Asian pear	T/E	Rosaceae
130	*Quercus glauca* Thumb.	Falant	Ring-cupped oak	T/N	Fagaceae
131	*Rhododendron arboreum* Smith	Lali guransa	Tree rhododendron	T/N	Ericaceae
132	*Ricinus communis* L.	Andir	Castor bean	S/E	Euphorbiaceae
133	*Salix tetrasperma* Roxb.	Bainsa	Indian willow	T/E	Salicaceae
134	*Sambucus hookeri* Rehder	Galeni	Elder	T/N	Sambucaceae
135	*Sapindus mukorossi* Gaertn.	Rittha	Soap berry	T/N	Sapindaceae
136	*Schefflera impressa* (C. B. Clarke) Harms	Simaal	Schefflera vine	T/N	Araliaceae
137	*Schima wallichii* (DC.) Korth.	Chilaune	Needlewood tree	T/N	Theaceae
138	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	Khayar	Cutch tree	T/N	Leguminosae
139	*Spathodea campanulata* P. Beauv		African tulip tree	T/E	Bignoniaceae

140	*Syzygium cumini* (L) Skeels	Jamuna	Malabar plum	T/N	Myrtaceae
141	*Syzygium jambos* (L.) Alston	Gulab jamun	Rose apple	T/N	Myrtaceae
142	*Tecoma stans* (L.) H. B. K.	Ghata pushpi	Yellow bell	S/E	Bignoniaceae
143	*Thespesia lampas* (Cav.) Dalz. & Gibs.	Ban kapas	Common mallow	S/N	Malvaceae
144	*Thuja orientalis* L.	Mayur Pankhi	Cedar	T/E	Cupressaceae
145	*Toona ciliata* M. Roem.	Tooni	Indian cedar	T/N	Meliaceae
146	*Trachycarpus* sp. H. Wendl.	Taad	Fan palm	T/N	Palmae
147	*Vitex negundo* L.	Simali	Five-leaved chaste tree	S/N	Verbenaceae
148	*Woodfordia fruticosa* (L.) Kurz	Dhangero	Fire flame bush	S/N	Lythraceae
149	*Zanthoxylum armatum* DC.	Timur	Prickly ash	T/N	Rutaceae
150	*Ziziphus incurva* Roxb.	Hade bayar	Bead plum	T/N	Rhamnaceae

Appendix II: List of TOFs plant species with specific wood density (ρ) used

SN	Plant species	ρ value	SN	Plant species	ρ value
1	*Acacia catechu*	0.96	76	*Jacaranda mimosifolia*	0.49
2	*Acacia nilotica*	0.58	77	*Jasminum mesneyi*	0.56
3	*Acer oblongum*	0.46	78	*Juglans nigra*	0.51
4	*Agave cantula*	0.56	79	*Juglans regia*	0.59
5	*Alangium chinense*	0.42	80	*Juniperus chinensis*	0.52
6	*Albizia julibrissin*	0.70	81	*Juniperus communis*	0.52
7	*Albizia procera*	0.64	82	*Juniperus indica*	0.55
8	*Alnus nepalensis*	0.40	83	*Juniperus recurva*	0.67
9	*Alstonia neriifolia*	0.67	84	*Lagerstroemia indica*	0.70
10	*Alstonia scholaris*	0.44	85	*Lagerstroemia parviflora*	0.85
11	*Anthocephalus chinensis*	0.60	86	*Lagerstroemia reginae*	0.58
12	*Araucaria bidwillii*	0.43	87	*Leucaena leucocephala*	0.54
13	*Araucaria columnaris*	0.58	88	*Ligustrum confusum*	0.67
14	*Araucaria heterophylla*	0.58	89	*Lindera pulcherrima*	0.85
15	*Areca catechu*	0.58	90	*Litchi chinensis*	0.68
16	*Atrocarpus integra*	0.56	91	*Litsea monopetala*	0.61
17	*Azadirachta indica*	0.69	92	*Macadamia integrifolia*	0.79
18	*Bambusa nepalensis*	0.35	93	*Madhuca longofolia*	0.68
19	*Bauhinia variegata*	0.70	94	*Mahonia nepalensis*	0.56
20	*Berberis asiatica*	0.56	95	*Mangifera indica*	0.68
21	*Borassus flabellifer*	0.87	96	*Magnolia soulangeana*	0.51
22	*Bougainvillea glabra*	0.56	97	*Malvaviscus arboreus*	0.43
23	*Brugmansia arborea*	0.56	98	*Manglietia insignis*	0.40
24	*Buchanania latifolia*	0.45	99	*Melia azedarch*	0.53

25	*Buddleja asiatica*	0.28	100	*Michelia champaka*	0.63
26	*Burretiokentia vieillardii*	0.58	101	*Michelia fuscata*	0.63
27	*Callistemon citrinus*	0.80	102	*Miliusa ventulina*	0.63
28	*Camellia japonica*	0.55	103	*Morus alba*	0.52
29	*Carica papaya*	0.16	104	*Murraya koenigii*	0.68
30	*Carya illinoensis*	0.60	105	*Musa paradisiaca*	0.75
31	*Caryota uens*	0.67	106	*Myrica esculenta*	0.58
32	*Cassia fistula*	0.96	107	*Myrsine capitellata*	0.67
33	*Cassia mimosaides*	0.90	108	*Nerium indicum*	0.60
34	*Casuarina equisetifolia*	0.83	109	*Nerium oleander* variegatum	0.88
35	*Cedrus deodara*	0.56	110	*Nyctanthes arbor-tristis*	0.55
36	*Celtis australis*	0.72	111	*Persea americana*	0.60
37	*Cestrum nocturnum*	0.56	112	*Persea duthiei*	0.68
38	*Choerospondias axillaris*	0.40	113	*Phoenix humilis*	0.56
39	*Cinnamomum camphora*	0.60	114	*Phoenix sylvestris*	0.64
40	*Cinnamomum tamala*	0.60	115	*Phyllanths emblica*	0.33
41	*Citrus aurantifolia*	0.67	116	*Pinus roxburghii*	0.65
42	*Citrus jambhiri*	0.67	117	*Platanus orientalis*	0.48
43	*Citrus limon*	0.56	118	*Podocarpus neriifolius*	0.38
44	*Citrus maxima*	0.78	119	*Populus jacquemontiana*	0.58
45	*Citrus reticulata*	0.67	120	*Prunus avium*	0.58
46	*Cotinus coggygria*	0.56	121	*Prunus cerasoides*	0.72
47	*Croton ruxburghii*	0.61	122	*Prunus domestica*	0.73
48	*Cycus pectinata*	0.67	123	*Prunus persica*	0.65
49	*Cyphomandra betaceae*	0.56	124	*Psidium guajava*	0.77
50	*Dalbergia sissoo*	0.76	125	*Punica granatum*	0.63
51	*Diospiros kaki*	0.70	126	*Pyrus communis*	0.66

52	*Diploknema butyracea*	0.63	127	*Pyrus crenata*	0.67
53	*Duranta erecta*	0.56	128	*Pyrus malus*	0.70
54	*Elaeocarpus sphaericus*	0.50	129	*Pyrus pashia*	0.67
55	*Eriobotrya japonica*	0.88	130	*Pyrus pyrifolia*	0.73
56	*Erythrina arborescens*	0.27	131	*Quercus glauca*	0.93
57	*Erythrina stricta*	0.27	132	*Rhododendron arboreum*	0.64
58	*Eucalyptus camaldulensis*	0.49	133	*Ricinus communis*	0.34
59	*Euphorbia pulcherrima*	0.56	134	*Salix tetrasperma*	0.50
60	*Ficus auriculata*	0.39	135	*Sambucus hookeri*	0.70
61	*Ficus benghalensis*	0.59	136	*Sappindus mukorossi*	0.70
62	*Ficus benjamina*	0.65	137	*Schefflera impress*	0.49
63	*Ficus elastica*	0.39	138	*Schima wallichii*	0.69
64	*Ficus lacor*	0.46	139	*Spathodea campanulata*	0.58
65	*Ficus neriifolia*	0.39	140	*Syzigium cumini*	0.77
66	*Ficus religeosa*	0.46	141	*Syzigium jambos*	0.69
67	*Ficus semicordata*	0.39	142	*Tecoma stans*	0.47
68	*Fraxinus floribunda*	0.77	143	*Thespesia lampas*	0.52
69	*Ginkgo biloba*	0.46	144	*Thuja orientalis*	0.38
70	*Gossypium arborium*	0.68	145	*Toona ciliata*	0.56
71	*Grevillea robusta*	0.57	146	*Trachycarpus* sp.	0.58
72	*Hibiscus brackenridgei*	0.56	147	*Vitex negundo*	0.56
73	*Hibiscus rosa-sinensis*	0.56	148	*Woodfordia fruticosa*	0.56
74	*Homalium napaulense*	0.67	149	*Zanthoxylum armatum*	0.72
75	*Ilex excelsa*	0.67	150	*Ziziphus incurva*	0.76

Appendix III: Number of trees outside forests by species and timber quality classes measured for the estimation of volume and biomass of the merchantable timber

S.N .	TOFs species	Vernacular name	Number of trees	
			Class A	Class B
1	*Acacia catechu*	Khayar		1
2	*Albizia julibrissin*	Rato siris	12	3
3	*Albizia procera*	Seto siris	4	
4	*Alnus nepalensis*	Uttis	5	14
5	*Araucaria bidwillii*	Dhengre sallo	5	1
6	*Araucaria heterophylla*	Dhengre salla	1	3
7	*Areca catechu*	Bhale supari	4	2
8	*Borassus flabellifer*	Taad	1	
9	*Buddleja asiatica*	Bhimsenpati		3
10	*Burretiokentia vieillardii*	Tiger palm		1
11	*Callistemon citrinus*	Kalki phool	1	8
12	*Casuarina equisetifolia*	Jangali jhau	1	3
13	*Celtis australis*	Khari	8	9
14	*Choerospondias axillaris*	Lapsi	15	5
15	*Cinnamomum camphora*	Kapoor	49	32
16	*Dalbergia sissoo*	Sisau	1	3
17	*Elaeocarpus sphaericus*	Rudraksha	2	
18	*Eucalyptus camaldulensis*	Masala	36	12
19	*Ficus auriculata*	Timilo		1
20	*Ficus benghalensis*	Bar		4
21	*Ficus benjamina*	Sami	1	
22	*Ficus elastica*	Rubber plant	1	2
23	*Ficus lacor*	Kabhro	8	
24	*Ficus religiosa*	Pipal	28	10
25	*Fraxinus floribunda*	Lankuri		6

26	*Grevillea robusta*	Kagiyo	67	36
27	*Homalium napaulense*	Falame kanda		1
28	*Jacaranda mimosifolia*	Nilo phool	22	17
29	*Juglans nigra*	Hade okhar	1	2
30	*Juglans regia*	Dante okhar	2	1
31	*Juniperus recurva*	Dhupi	1	1
32	*Lindera pulcherrima*	Shyal fushre		1
33	*Litsea monopetala*	Kutmiro	3	
34	*Mangifera indica*	Aanp		2
35	*Melia azedarach*	Bakaino	1	
36	*Michelia champaka*	Champ	1	1
37	*Myrica esculenta*	Kafal		1
38	*Nyctanthes arbor-tristis*	Parijat	2	
39	*Persea americana*	Ghiu phal	2	3
40	*Pinus roxburghii*	Khote salla	5	18
41	*Platanus orientalis*	Chinar	5	
42	*Podocarpus neriifolius*	Gunsi	2	
43	*Populus jacquemontiana*	Lahare pipal	23	12
44	*Prunus cerasoides*	Painyu	3	1
45	*Pyrus pashia*	Mayal		1
46	*Rhododendron arboreum*	Lali gurans		1
47	*Salix tetrasperma*	Bainsa		2
48	*Schima wallichii*	Chilaune	17	5
49	*Spathodea campanulata*		1	
50	*Syzygium cumini*	Jamun	6	7
51	*Syzygium jambos*	Gulab jamun	2	
52	*Thuja orientalis*	Mayur pankhi	12	6
53	*Ziziphus incurva*	Hade bayar	8	

Appendix IV: Market price (MP) of merchantable timber and firewood in Kathmandu valley, Nepal. *Maximum, **Minimum and ***Average (MP valued in September 2020)

		MP of timber class A (cu ft. $^{-1}$)			MP of timber class B (cu ft. $^{-1}$)			MP of fire wood
SN	**TOFs species**	**Max***	**Min****	**Av*****	**Max**	**Min**	**Av**	**(kg^{-1})**
1	*Acacia catechu*	1100		1100	900		900	9.86
2	*Albizia julibrissin*			1452			1165	9.86
3	*Albizia procera*			1452			1165	9.86
4	*Alnus nepalensis*	800	525	663	700		700	6
5	*Araucaria bidwillii*	1300	1050	1175	1150		1150	6
6	*Araucaria heterophylla*	1200	1100	1150	1000		1000	6
7	*Areca catechu*	1300		1300	900		900	9.86
8	*Borassus flabellifer*			1452			1165	9.86
9	*Buddleja asiatica*			1452			1165	9.86
10	*Burretiokentia vieillardii*			1452			1165	9.86
11	*Callistemon citrinus*			1452			1165	9.86
12	*Casuarina equisetifolia*			1452			1165	9.86
13	*Celtis australis*	1000		1000	700		700	9.86
14	*Choerospondias axillaris*	700	650	675	600		600	6
15	*Cinnamomum camphora*	2200	3200	2700	2000		2000	9.86
16	*Dalbergia sissoo*	2500	6500	4500	2000	3000	2500	16
17	*Elaeocarpus sphaericus*			1452			1165	9.86
18	*Eucalyptus camaldulensis*	1300	2000	1650	1100	1400	1250	16
19	*Ficus auriculata*			1452			1165	9.86
20	*Ficus benghalensis*			1452			1165	9.86
21	*Ficus benjamina*			1452			1165	9.86
22	*Ficus elastica*			1452			1165	9.86
23	*Ficus lacor*			1452			1165	9.86
24	*Ficus religeosa*		700	700		600	600	9.86
25	*Fraxinus floribunda*			1452			1165	9.86
26	*Grevillea robusta*		800	800			1165	7

27	*Homalium napaulense*			1452			1165	9.86
28	*Jacaranda mimosifolia*			1452			1165	9.86
29	*Juglans nigra*			1452			1165	9.86
30	*Juglans regia*			1452			1165	9.86
31	*Juniperus recurva*			1452			1165	9.86
32	*Lindera pulcherrima*			1452			1165	9.86
33	*Litsea monopetala*			1452			1165	9.86
34	*Magnifera indica*		1050	1050			1165	8
35	*Melia azedarch*			1452			1165	9.86
36	*Michelia champaka*			1452			1165	9.86
37	*Myrica esculenta*			1452			1165	9.86
38	*Persea americana*			1452			1165	9.86
39	*Phoenix sylvestris*	1000		1000	900		900	9.86
40	*Pinus roxburghii*	1800	3600	2700	2700		2700	16
41	*Platanus orientalis*			1452			1165	9.86
42	*Podocarpus neriifolius*			1452			1165	9.86
43	*Populus jacquemontiana*		550	550			1165	7
44	*Prunus cerasoides*		900	900		800	800	7
45	*Pyrus pashia*			1452			1165	9.86
46	*Rhododendron arboreum*	1400		1400	1100		1100	9.86
47	*Salix tetrasperma*			1452			1165	9.86
48	*Schima wallichii*	1100	650	875	800		800	6
49	*Spathodea campanulata*			1452			1165	9.86
50	*Syzigium cumini*	1400	3000	2200	1200		1200	16
51	*Syzigium jambos*		3050	3050			1165	15
52	*Thuja orientalis*			1452			1165	9.86
53	*Ziziphus incurva*		800	800			1165	9.86
				1452			1165	9.86
54	*Bambusa nepalensis***							

**Market price ranged from NPR 210-420 with the average price NPR 315.

(Market price valued in September 2020)

Appendix V: Total Market value (MV) of class A timber, class B timber, total timber, firewood and wood in the study area (Market price valued in September 2020)

S.N.	TPF species	Total MV of timber Class A (NPR ha^{-1})	Total MV of timber Class B (NPR ha^{-1})	Total MV of total timber (NPR ha^{-1})	Total MV of fire wood (NPR ha^{-1})	Total MV of wood (NPR ha^{-1})
1	*Cinnamomum camphora*	229851.10	17399.08	247250.18	48850.59	296100.77
2	*Schima wallichii*	130209.91	5045.35	135255.26	8623.72	143878.98
3	*Pinus roxburghii*	35764.81	16550.56	52315.37	63792.83	116108.19
4	*Eucalyptus camaldulensis*	52300.14	1885.26	54185.41	42417.02	96602.43
5	*Ficus religeosa*	38367.50	2431.66	40799.16	34526.56	75325.72
6	*Syzigium cumini*	32545.79	5612.76	38158.55	36249.56	74408.11
7	*Grevillea robusta*	32433.85	6931.04	39364.90	32311.10	71676.00
8	*Jacaranda mimosifolia*	36207.46	4149.46	40356.92	19877.31	60234.23
9	*Populus jacquemontiana*	11655.63	6645.28	18300.91	21232.49	39533.40
10	*Celtis australis*	6261.26	3213.15	9474.41	27060.54	36534.95
11	*Albizia julibrissin*	13862.81	759.17	14621.98	11810.10	26432.09
12	*Araucaria bidwillii*	17991.43	505.37	18496.81	5184.19	23680.99
13	*Thuja orientalis*	6946.61	1153.78	8100.39	15552.98	23653.36
14	*Callistemon citrinus*	2042.93	5415.71	7458.64	11783.83	19242.47
15	*Ficus lacor*	16951.15	0.00	16951.15	708.73	17659.88
16	*Litsea monopetala*	17094.64	0.00	17094.64	521.06	17615.70
17	*Choerospondias axillaris*	6290.36	973.81	7264.17	7726.15	14990.31
18	*Rhododendron arboreum*	0.00	818.14	818.14	13173.07	13991.21
19	*Syzigium jambos*	13333.15	0.00	13333.15	322.73	13655.89

20	*Dalbergia sissoo*	4759.29	1333.06	6092.35	6428.49	12520.84
21	*Morus australis*	0.00	0.00	0.00	10852.03	10852.03
22	*Ziziphus incurva*	8216.28	0.00	8216.28	2548.88	10765.16
23	*Melia azedarch*	385.14	0.00	385.14	8431.25	8816.39
24	*Casuarina equisetifolia*	686.48	1044.48	1730.96	6430.28	8161.24
25	*Alnus nepalensis*	1499.03	1473.51	2972.54	5053.95	8026.49
26	*Juglans nigra*	502.47	1382.57	1885.05	5856.57	7741.62
27	*Albizia procera*	5508.75	0.00	5508.75	1760.91	7269.66
28	*Salix tetrasperma*	0.00	527.40	527.40	6617.94	7145.34
29	*Ficus elastica*	2739.55	271.11	3010.66	4105.11	7115.77
30	*Fraxinus floribunda*	0.00	3489.98	3489.98	2813.24	6303.22
31	*Persea americana*	3234.73	950.37	4185.10	1894.76	6079.86
32	*Araucaria heterophylla*	2004.87	1765.63	3770.49	1700.37	5470.86
33	*Anthocephalus chinensis*	0.00	0.00	0.00	4936.62	4936.62
34	*Prunus cerasoides*	1147.91	376.18	1524.08	2416.24	3940.33
35	*Magnifera indica*	0.00	507.61	507.61	3343.07	3850.68
36	*Ficus benjamina*	1173.03	0.00	1173.03	2326.47	3499.50
37	*Cassia fistula*	0.00	0.00	0.00	3238.48	3238.48
38	*Areca catechu*	1447.31	534.31	1981.63	1250.63	3232.26
39	*Ficus benghalensis*	0.00	575.30	575.30	2385.13	2960.44
40	*Juniperus recurva*	758.14	379.92	1138.05	1580.33	2718.38
41	*Borassus flabellifer*	1619.02	0.00	1619.02	891.65	2510.67
42	*Citrus maxima*	0.00	0.00	0.00	2414.72	2414.72
43	*Platanus orientalis*	2104.49	0.00	2104.49	302.98	2407.47
44	*Podocarpus neriifolius*	2140.32	0.00	2140.32	177.74	2318.06
45	*Michelia champaka*	1844.05	0.00	1844.05	417.18	2261.23
46	*Lagerstroemia indica*	0.00	0.00	0.00	2142.11	2142.11
47	*Juglans regia*	1202.57	219.15	1421.72	660.68	2082.39

48	*Pyrus pyrifolia*	0.00	0.00	0.00	2053.11	2053.11
49	*Elaeocarpus sphaericus*	1086.35	0.00	1086.35	638.96	1725.31
50	*Myrica esculenta*	0.00	773.83	773.83	768.61	1542.44
51	*Homalium napaulense*	1423.89	0.00	1423.89	8.06	1431.95
52	*Psidium guajava*	0.00	0.00	0.00	1409.06	1409.06
53	*Diospiros kaki*	0.00	0.00	0.00	1348.03	1348.03
54	*Spathodea campanulata*	1018.55	0.00	1018.55	118.54	1137.09
55	*Nyctanthes arbor-tristis*	0.00	0.00	0.00	986.84	986.84
56	*Buddleja asiatica*	0.00	307.13	307.13	660.85	967.99
57	*Pyrus pashia*	0.00	170.64	170.64	759.00	929.65
58	*Manglietia insignis*	0.00	0.00	0.00	900.95	900.95
59	*Erythrina arborescens*	0.00	0.00	0.00	785.68	785.68
60	*Prunus domestica*	0.00	0.00	0.00	744.51	744.51
61	*Prunus persica*	0.00	0.00	0.00	734.26	734.26
62	*Lindera pulcherrima*	0.00	0.00	0.00	630.67	630.67
63	*Nerium indicum*	0.00	0.00	0.00	613.95	613.95
64	*Pyrus malus*	0.00	0.00	0.00	609.22	609.22
65	*Citrus jambhiri*	0.00	0.00	0.00	546.68	546.68
66	*Carya illinoensis*	0.00	0.00	0.00	441.64	441.64
67	*Bauhinia variegata*	0.00	0.00	0.00	431.49	431.49
68	*Cycus pectinata*	0.00	0.00	0.00	430.36	430.36
69	*Phoenix humilis*	0.00	0.00	0.00	383.50	383.50
70	*Bougainvillea glabra*	0.00	0.00	0.00	382.51	382.51
71	*Musa paradisiaca*	0.00	0.00	0.00	381.83	381.83
72	*Phoenix sylvestris*	0.00	203.02	203.02	170.06	373.08
73	*Persea duthiei*	0.00	0.00	0.00	360.86	360.86
74	*Ficus auriculata*	0.00	170.71	170.71	165.08	335.79
75	*Burretiokentia vieillardii*	0.00	181.61	181.61	128.05	309.65

76	*Macadamia integrifolia*	0.00	0.00	0.00	298.33	298.33
77	*Ilex excelsa*	0.00	0.00	0.00	295.60	295.60
78	*Juniperus indica*	0.00	0.00	0.00	284.71	284.71
79	*Litchi chinensis*	0.00	0.00	0.00	264.11	264.11
80	*Citrus aurantifolia*	0.00	0.00	0.00	246.76	246.76
81	*Sambucus hookeri*	0.00	0.00	0.00	245.08	245.08
82	*Acacia catechu*	0.00	230.85	230.85	2.22	233.07
83	*Caryota uens*	0.00	0.00	0.00	193.38	193.38
84	*Michelia fuscata*	0.00	0.00	0.00	167.78	167.78
85	*Juniperus chinensis*	0.00	0.00	0.00	167.70	167.70
86	*Leucaena leucocephala*	0.00	0.00	0.00	159.42	159.42
87	*Punica granatum*	0.00	0.00	0.00	158.83	158.83
88	*Phyllanths emblica*	0.00	0.00	0.00	154.19	154.19
89	*Myrsine capitellata*	0.00	0.00	0.00	90.57	90.57
90	*Cestrum nocturnum*	0.00	0.00	0.00	90.46	90.46
91	*Azadirachta indica*	0.00	0.00	0.00	86.06	86.06
92	*Toona ciliate*	0.00	0.00	0.00	81.35	81.35
93	*Erythrina stricta*	0.00	0.00	0.00	73.10	73.10
94	*Quercus glauca*	0.00	0.00	0.00	65.27	65.27
95	*Madhuca longofolia*	0.00	0.00	0.00	64.32	64.32
96	*Thespesia lampas*	0.00	0.00	0.00	64.19	64.19
97	*Ficus semicordata*	0.00	0.00	0.00	64.01	64.01
98	*Acacia nilotica*	0.00	0.00	0.00	63.65	63.65
99	*Tecoma stans*	0.00	0.00	0.00	61.21	61.21
100	*Lagerstoemia reginae*	0.00	0.00	0.00	59.11	59.11
101	*Cedrus deodara*	0.00	0.00	0.00	56.25	56.25
102	*Alstonia scholaris*	0.00	0.00	0.00	54.95	54.95
103	*Ficus neriifolia*	0.00	0.00	0.00	53.49	53.49

104	*Zanthoxylum armatum*	0.00	0.00	0.00	45.03	45.03
105	*Duranta erecta*	0.00	0.00	0.00	44.69	44.69
106	*Cinnamomum tamala*	0.00	0.00	0.00	40.11	40.11
107	*Prunus avium*	0.00	0.00	0.00	30.71	30.71
108	*Nerium oleander variegatum*	0.00	0.00	0.00	30.36	30.36
109	*Brugmansia arborea*	0.00	0.00	0.00	30.34	30.34
110	*Araucaria columnaris*	0.00	0.00	0.00	30.23	30.23
111	*Cassia mimosaides*	0.00	0.00	0.00	26.09	26.09
112	*Lagerstroemia parviflora*	0.00	0.00	0.00	25.70	25.70
113	*Euphorbia pulcherrima*	0.00	0.00	0.00	25.22	25.22
114	*Citrus reticulata*	0.00	0.00	0.00	21.91	21.91
115	*Croton ruxburghii*	0.00	0.00	0.00	20.90	20.90
116	*Pyrus crenata*	0.00	0.00	0.00	20.03	20.03
117	*Ginkgo biloba*	0.00	0.00	0.00	18.92	18.92
118	*Woodfordia fruticosa*	0.00	0.00	0.00	18.57	18.57
119	*Trachycarpus sp.*	0.00	0.00	0.00	17.59	17.59
120	*Ligustrum confusum*	0.00	0.00	0.00	16.33	16.33
121	*Schefflera impress*	0.00	0.00	0.00	15.97	15.97
122	*Hibiscus rosa-sinensis*	0.00	0.00	0.00	15.24	15.24
123	*Miliusa ventulina*	0.00	0.00	0.00	14.48	14.48
124	*Atrocarpus integra*	0.00	0.00	0.00	12.28	12.28
125	*Malvaviscus arboreus*	0.00	0.00	0.00	12.21	12.21
126	*Berberis asiatica*	0.00	0.00	0.00	10.92	10.92
127	*Murraya koenigii*	0.00	0.00	0.00	10.82	10.82
128	*Mahonia nepaulensis*	0.00	0.00	0.00	9.45	9.45
129	*Gossypium arborium*	0.00	0.00	0.00	9.34	9.34
130	*Carica papaya*	0.00	0.00	0.00	8.36	8.36

131	*Citrus limon*	0.00	0.00	0.00	7.78	7.78
132	*Sappindus mukorossi*	0.00	0.00	0.00	7.16	7.16
133	*Diploknema butyracea*	0.00	0.00	0.00	6.88	6.88
134	*Acer oblongum*	0.00	0.00	0.00	6.47	6.47
135	*Buchanania latifolia*	0.00	0.00	0.00	6.24	6.24
136	*Magnolia soulangeana*	0.00	0.00	0.00	6.07	6.07
137	*Juniperus communis*	0.00	0.00	0.00	5.19	5.19
138	*Agave cantula*	0.00	0.00	0.00	4.08	4.08
139	*Pyrus communis*	0.00	0.00	0.00	3.12	3.12
140	*Hibiscus brackenridgei*	0.00	0.00	0.00	3.08	3.08
141	*Alangium chinense*	0.00	0.00	0.00	2.17	2.17
142	*Jasminum mesneyi*	0.00	0.00	0.00	1.98	1.98
143	*Alstonia neriifolia*	0.00	0.00	0.00	1.83	1.83
144	*Cotinus coggygria*	0.00	0.00	0.00	1.70	1.70
145	*Cyphomandra betaceae*	0.00	0.00	0.00	1.70	1.70
146	*Ricinus communis*	0.00	0.00	0.00	1.26	1.26
147	*Camellia japonica*	0.00	0.00	0.00	1.26	1.26
148	*Vitex negundo*	0.00	0.00	0.00	1.02	1.02
149	*Eriobotrya japonica*	0.00	0.00	0.00	0.71	0.71
150	*Bambusa nepalensis*					3297.32
	Total	**746612.77**	**96357.93**	**842970.71**	**516612.30**	**1362880.32**

Appendix VI: Total Market value (MV) of class A timber, class B timber total timber, firewood and wood in the urban stratum (Market price valued in September 2020)

S.N.	TOFs species	Total MV of timber Class A (NPR ha^{-1})	Total MV of timber Class B (NPR ha^{-1})	Total MV of total timber (NPR ha^{-1})	Total MV of fire wood (NPR ha^{-1})	Total MV of wood (NPR ha^{-1})
1	*Cinnamomum camphora*	218141.88	31076.60	249218.48	65937.02	315155.50
2	*Pinus roxburghii*	79497.15	22072.30	101569.45	86736.31	188305.76
3	*Grevillea robusta*	46577.99	815.28	47393.26	52477.73	99870.99
4	*Jacaranda mimosifolia*	56982.34	8298.60	65280.95	27181.30	92462.25
5	*Ficus religeosa*	66501.12	5147.44	71648.56	4221.87	75870.43
6	*Populus jacquemontiana*	23080.86	4349.91	27430.76	37544.38	64975.15
7	*Albizia julibrissin*	37363.78	1803.03	39166.81	24259.07	63425.88
8	*Litsea monopetala*	40599.77	0.00	40599.77	17241.14	57840.91
9	*Celtis australis*	10279.77	6055.56	16335.33	25971.62	42306.95
10	*Ziziphus incurva*	28416.77	0.00	28416.77	10216.07	38632.84
11	*Callistemon citrinus*	4851.97	8508.65	13360.61	11984.08	25344.70
12	*Choerospondias axillaris*	13848.19	1388.81	15237.01	8544.26	23781.27
13	*Eucalyptus camaldulensis*	13287.23	1469.27	14756.51	8507.40	23263.91
14	*Syzigium jambos*	12095.47	0.00	12095.47	9118.30	21213.77
15	*Ficus lacor*	27.73	0.00	27.73	13319.88	13347.61
16	*Dalbergia sissoo*	0.00	1957.63	1957.63	8156.72	10114.35
17	*Elaeocarpus sphaericus*	2580.08	0.00	2580.08	6646.44	9226.52
18	*Ficus elastica*	6506.43	0.00	6506.43	1683.22	8189.65
19	*Melia azedarch*	0.00	0.00	0.00	6904.49	6904.49

20	*Araucaria heterophylla*	4761.56	0.00	4761.56	2001.45	6763.01
21	*Areca catechu*	3437.37	1269.00	4706.37	1793.72	6500.09
22	*Casuarina equisetifolia*	1630.39	2480.64	4111.03	2374.40	6485.43
23	*Araucaria bidwillii*	1285.58	1200.26	2485.84	3722.20	6208.04
24	*Salix tetrasperma*	0.00	0.00	0.00	5855.73	5855.73
25	*Podocarpus neriifolius*	5083.27	0.00	5083.27	422.13	5505.40
26	*Thuja orientalis*	2642.17	802.64	3444.80	1933.69	5378.49
27	*Ficus benjamina*	2785.94	0.00	2785.94	2417.31	5203.25
28	*Citrus maxima*	0.00	0.00	0.00	4855.18	4855.18
29	*Prunus cerasoides*	1956.38	893.42	2849.80	1799.36	4649.15
30	*Borassus flabellifer*	3845.17	0.00	3845.17	681.79	4526.96
31	*Schima wallichii*	0.00	545.38	545.38	3949.17	4494.55
32	*Syzigium cumini*	2252.60	0.00	2252.60	1819.19	4071.79
33	*Juglans regia*	2856.10	0.00	2856.10	1128.44	3984.54
34	*Ficus benghalensis*	0.00	1366.35	1366.35	2417.31	3783.66
35	*Juglans nigra*	1193.37	578.73	1772.10	1503.91	3276.01
36	*Spathodea campanulata*	2419.06	0.00	2419.06	281.54	2700.59
37	*Lindera pulcherrima*	0.00	1519.97	1519.97	1139.44	2659.41
38	*Nyctanthes arbor-tristis*	1779.44	0.00	1779.44	611.27	2390.71
39	*Manglietia insignis*	0.00	0.00	0.00	2030.45	2030.45
40	*Buddleja asiatica*	0.00	729.44	729.44	1186.28	1915.72
41	*Pyrus pyrifolia*	0.00	0.00	0.00	1862.01	1862.01
42	*Magnifera indica*	0.00	505.68	505.68	1235.19	1740.87
43	*Persea Americana*	0.00	1210.42	1210.42	334.99	1545.40

44	*Morus australis*	0.00	0.00	0.00	1475.62	1475.62
45	*Lagerstroemia indica*	0.00	0.00	0.00	1165.61	1165.61
46	*Pyrus pashia*	0.00	0.00	0.00	1054.78	1054.78
47	*Carya illinoensis*	0.00	0.00	0.00	1048.91	1048.91
48	*Prunus domestica*	0.00	0.00	0.00	886.63	886.63
49	*Psidium guajava*	0.00	0.00	0.00	880.43	880.43
50	*Phoenix humilis*	0.00	624.14	624.14	242.04	866.18
51	*Bauhinia variegate*	0.00	0.00	0.00	793.05	793.05
52	*Acacia catechu*	0.00	548.27	548.27	200.16	748.43
53	*Ficus auriculata*	0.00	405.44	405.44	185.81	591.25
54	*Burretiokentia vieillardii*	0.00	431.31	431.31	152.05	583.37
55	*Albizia procera*	0.00	0.00	0.00	563.25	563.25
56	*Diospiros kaki*	0.00	0.00	0.00	526.05	526.05
57	*Rhododendron arboreum*	0.00	0.00	0.00	522.36	522.36
58	*Prunus persica*	0.00	0.00	0.00	501.73	501.73
59	*Michelia champaka*	0.00	0.00	0.00	369.66	369.66
60	*Juniperus indica*	0.00	0.00	0.00	357.43	357.43
61	*Caryota uens*	0.00	0.00	0.00	353.78	353.78
62	*Juniperus chinensis*	0.00	0.00	0.00	324.97	324.97
63	*Bougainvillea glabra*	0.00	0.00	0.00	303.61	303.61
64	*Sambucus hookeri*	0.00	0.00	0.00	290.09	290.09
65	*Alnus nepalensis*	0.00	200.38	200.38	48.89	249.26
66	*Myrsine capitellata*	0.00	0.00	0.00	215.11	215.11
67	*Cestrum nocturnum*	0.00	0.00	0.00	214.84	214.84
68	*Azadirachta indica*	0.00	0.00	0.00	200.99	200.99
69	*Punica granatum*	0.00	0.00	0.00	198.72	198.72

70	*Toona ciliate*	0.00	0.00	0.00	193.20	193.20
71	*Erythrina stricta*	0.00	0.00	0.00	173.61	173.61
72	*Acacia nilotica*	0.00	0.00	0.00	151.16	151.16
73	*Lagerstoemia reginae*	0.00	0.00	0.00	140.39	140.39
74	*Cedrus deodara*	0.00	0.00	0.00	96.65	96.65
75	*Prunus avium*	0.00	0.00	0.00	72.93	72.93
76	*Alstonia scholaris*	0.00	0.00	0.00	71.31	71.31
77	*Cassia mimosaides*	0.00	0.00	0.00	61.97	61.97
78	*Lagerstroemia parviflora*	0.00	0.00	0.00	61.04	61.04
79	*Murraya koenigii*	0.00	0.00	0.00	54.64	54.64
80	*Croton ruxburghii*	0.00	0.00	0.00	49.65	49.65
81	*Woodfordia fruticosa*	0.00	0.00	0.00	44.11	44.11
82	*Euphorbia pulcherrima*	0.00	0.00	0.00	43.15	43.15
83	*Trachycarpus sp.*	0.00	0.00	0.00	41.77	41.77
84	*Anthocephalus chinensis*	0.00	0.00	0.00	40.80	40.80
85	*Miliusa ventulina*	0.00	0.00	0.00	34.38	34.38
86	*Juniperus recurva*	0.00	0.00	0.00	32.15	32.15
87	*Citrus aurantifolia*	0.00	0.00	0.00	32.15	32.15
88	*Atrocarpus integra*	0.00	0.00	0.00	29.16	29.16
89	*Schefflera impress*	0.00	0.00	0.00	26.83	26.83
90	*Mahonia nepaulensis*	0.00	0.00	0.00	22.44	22.44
91	*Gossypium arborium*	0.00	0.00	0.00	21.38	21.38
92	*Hibiscus rosa-sinensis*	0.00	0.00	0.00	16.43	16.43
93	*Diploknema butyracea*	0.00	0.00	0.00	16.35	16.35
94	*Buchanania latifolia*	0.00	0.00	0.00	14.81	14.81

95	*Carica papaya*	0.00	0.00	0.00	11.79	11.79
96	*Brugmansia arborea*	0.00	0.00	0.00	11.73	11.73
97	*Nerium indicum*	0.00	0.00	0.00	11.54	11.54
98	*Agave cantula*	0.00	0.00	0.00	9.70	9.70
99	*Pyrus communis*	0.00	0.00	0.00	7.40	7.40
100	*Alangium chinense*	0.00	0.00	0.00	5.15	5.15
101	*Ilex excelsa*	0.00	0.00	0.00	4.35	4.35
102	*Malvaviscus arboreus*	0.00	0.00	0.00	4.22	4.22
103	*Citrus limon*	0.00	0.00	0.00	3.33	3.33
104	*Cycus pectinata*	0.00	0.00	0.00	2.84	2.84
105	*Cyphomandra betaceae*	0.00	0.00	0.00	2.84	2.84
106	*Pyrus crenata*	0.00	0.00	0.00	2.72	2.72
107	*Hibiscus brackenridgei*	0.00	0.00	0.00	2.54	2.54
108	*Leucaena leucocephala*	0.00	0.00	0.00	1.53	1.53
109	*Duranta erecta*	0.00	0.00	0.00	1.19	1.19
	Total	**698566.90**	**108254.54**	**806821.45**	**488709.35**	**1295530.80**

Appendix VII: Total Market value (MV) of class A timber, class B timber total timber, firewood and wood in the suburban stratum (Market price valued in September 2020)

S.N.	TOFs species	Total MV of timber Class A (NPR ha^{-1})	Total MV of timber Class B (NPR ha^{-1})	Total MV of timber (NPR ha^{-1})	Total MV of firewood (NPR ha^{-1})	Total MV of wood (NPR ha^{-1})
1	*Syzigium cumini*	90463.58	16069.40	106532.98	69292.58	175825.56
2	*Eucalyptus camaldulensis*	116498.43	3626.36	120124.79	43566.07	163690.86
3	*Pinus roxburghii*	6562.96	11555.17	18118.13	91759.95	109878.08
4	*Grevillea robusta*	36709.76	7373.00	44082.76	20351.36	64434.12
5	*Cinnamomum camphora*	35550.69	3884.10	39434.79	18590.60	58025.39
6	*Ficus religeosa*	12719.51	0.00	12719.51	23900.10	36619.61
7	*Jacaranda mimosifolia*	20164.82	1876.16	22040.98	13853.31	35894.29
8	*Celtis australis*	1075.70	0.00	1075.70	28165.46	29241.16
9	*Populus jacquemontiana*	5546.74	2249.78	7796.52	19240.47	27036.99
10	*Thuja orientalis*	5176.58	2692.54	7869.13	16631.19	24500.31
11	*Dalbergia sissoo*	13625.91	1456.68	15082.59	6972.09	22054.68
12	*Albizia procera*	15771.63	0.00	15771.63	4362.51	20134.14
13	*Persea Americana*	9261.08	1261.78	10522.86	6990.81	17513.67
14	*Callistemon citrinus*	0.00	3489.63	3489.63	10963.11	14452.74
15	*Melia azedarch*	1102.66	0.00	1102.66	11750.18	12852.83
16	*Salix tetrasperma*	0.00	1509.94	1509.94	8109.41	9619.36
17	*Alnus nepalensis*	317.51	0.00	317.51	8460.25	8777.76
18	*Platanus orientalis*	6562.96	0.00	6562.96	1905.56	8468.52
19	*Albizia julibrissin*	4425.72	0.00	4425.72	2311.63	6737.36
20	*Michelia champaka*	1948.49	1336.32	3284.81	1027.14	4311.95

21	*Ficus benjamina*	0.00	0.00	0.00	3746.69	3746.69
22	*Choerospondias axillaris*	0.00	1113.85	1113.85	2592.33	3706.18
23	*Juniperus recurva*	0.00	0.00	0.00	3663.34	3663.34
24	*Ficus elastica*	0.00	776.18	776.18	2532.25	3308.43
25	*Psidium guajava*	0.00	0.00	0.00	2680.57	2680.57
26	*Lagerstroemia indica*	0.00	0.00	0.00	2267.55	2267.55
27	*Schima wallichii*	0.00	0.00	0.00	2228.98	2228.98
28	*Nyctanthes arbor-tristis*	0.00	0.00	0.00	1934.05	1934.05
29	*Nerium indicum*	0.00	0.00	0.00	1297.75	1297.75
30	*Pyrus pashia*	0.00	488.55	488.55	689.38	1177.93
31	*Fraxinus floribunda*	0.00	0.00	0.00	1073.71	1073.71
32	*Ficus benghalensis*	0.00	0.00	0.00	980.59	980.59
33	*Citrus maxima*	0.00	0.00	0.00	909.40	909.40
34	*Ilex excelsa*	0.00	0.00	0.00	840.25	840.25
35	*Persea duthiei*	0.00	0.00	0.00	835.80	835.80
36	*Prunus cerasoides*	0.00	0.00	0.00	657.47	657.47
37	*Pyrus pyrifolia*	0.00	0.00	0.00	656.44	656.44
38	*Borassus flabellifer*	0.00	0.00	0.00	595.64	595.64
39	*Litsea monopetala*	0.00	0.00	0.00	570.37	570.37
40	*Mangifera indica*	0.00	0.00	0.00	407.03	407.03
41	*Bauhinia variegate*	0.00	0.00	0.00	368.94	368.94
42	*Araucaria bidwillii*	0.00	0.00	0.00	359.50	359.50
43	*Musa paradisiaca*	0.00	0.00	0.00	304.09	304.09
44	*Morus australis*	0.00	0.00	0.00	300.92	300.92
45	*Prunus domestica*	0.00	0.00	0.00	222.97	222.97

46	*Macadamia integrifolia*	0.00	0.00	0.00	205.26	205.26
47	*Quercus glauca*	0.00	0.00	0.00	186.86	186.86
48	*Tecoma stans*	0.00	0.00	0.00	175.25	175.25
49	*Punica granatum*	0.00	0.00	0.00	165.48	165.48
50	*Ficus auriculata*	0.00	0.00	0.00	163.78	163.78
51	*Sambucus hookeri*	0.00	0.00	0.00	152.22	152.22
52	*Erythrina stricta*	0.00	0.00	0.00	151.56	151.56
53	*Elaeocarpus sphaericus*	0.00	0.00	0.00	142.61	142.61
54	*Juglans nigra*	0.00	0.00	0.00	139.43	139.43
55	*Zanthoxylum armatum*	0.00	0.00	0.00	128.92	128.92
56	*Caryota uens*	0.00	0.00	0.00	127.17	127.17
57	*Duranta erecta*	0.00	0.00	0.00	126.53	126.53
58	*Cinnamomum tamala*	0.00	0.00	0.00	114.82	114.82
59	*Nerium oleander variegatum*	0.00	0.00	0.00	102.67	102.67
60	*Prunus persica*	0.00	0.00	0.00	93.89	93.89
61	*Araucaria heterophylla*	0.00	0.00	0.00	83.56	83.56
62	*Thespesia lampas*	0.00	0.00	0.00	79.43	79.43
63	*Buddleja asiatica*	0.00	0.00	0.00	79.41	79.41
64	*Brugmansia arborea*	0.00	0.00	0.00	72.71	72.71
65	*Alstonia scholaris*	0.00	0.00	0.00	71.36	71.36
66	*Ficus lacor*	0.00	0.00	0.00	63.76	63.76
67	*Citrus reticulata*	0.00	0.00	0.00	62.72	62.72
68	*Ginkgo biloba*	0.00	0.00	0.00	54.16	54.16
69	*Pyrus crenata*	0.00	0.00	0.00	53.46	53.46

70	*Juniperus indica*	0.00	0.00	0.00	49.44	49.44
71	*Cedrus deodara*	0.00	0.00	0.00	44.54	44.54
72	*Diospiros kaki*	0.00	0.00	0.00	41.65	41.65
73	*Citrus aurantifolia*	0.00	0.00	0.00	34.67	34.67
74	*Phyllanths emblica*	0.00	0.00	0.00	34.12	34.12
75	*Bougainvillea glabra*	0.00	0.00	0.00	28.74	28.74
76	*Manglietia insignis*	0.00	0.00	0.00	21.51	21.51
77	*Sappindus mukorossi*	0.00	0.00	0.00	20.51	20.51
78	*Acer oblongum*	0.00	0.00	0.00	18.54	18.54
79	*Citrus jambhiri*	0.00	0.00	0.00	14.97	14.97
80	*Juniperus communis*	0.00	0.00	0.00	14.85	14.85
81	*Litchi chinensis*	0.00	0.00	0.00	14.05	14.05
82	*Carica papaya*	0.00	0.00	0.00	11.70	11.70
83	*Ficus neriifolia*	0.00	0.00	0.00	9.52	9.52
84	*Leucaena leucocephala*	0.00	0.00	0.00	8.54	8.54
85	*Lindera pulcherrima*	0.00	0.00	0.00	5.72	5.72
86	*Euphorbia pulcherrima*	0.00	0.00	0.00	4.78	4.78
87	*Azadirachta indica*	0.00	0.00	0.00	4.11	4.11
88	*Vitex negundo*	0.00	0.00	0.00	2.92	2.92
89	*Eriobotrya japonica*	0.00	0.00	0.00	2.03	2.03
90	*Bambusa nepalensis*					480.60
	Total	**383484.73**	**60759.45**	**444244.18**	**444103.69**	**888828.47**

Appendix VIII: Total Market value (MV) of class A timber, class B timber total timber, firewood and wood in the rural stratum (Market price valued in September 2020)

S.N.	TOFs species	Total MV of timber Class A (NPR ha^{-1})	Total MV of timber Class B (NPR ha^{-1})	Total MV of timber (NPR ha^{-1})	Total MV of fire wood (NPR ha^{-1})	Total MV of wood (NPR ha^{-1})
1	*Cinnamomum camphora*	530006.08	13048.76	543054.83	48601.00	591655.83
2	*Eucalyptus camaldulensis*	57242.12	0.00	57242.12	92461.20	149703.32
3	*Araucaria bidwillii*	75980.80	0.00	75980.80	14848.05	90828.86
4	*Schima wallichii*	69857.04	5333.48	75190.52	15101.95	90292.47
5	*Ficus religeosa*	25795.52	1150.89	26946.41	21470.64	48417.05
6	*Pinus roxburghii*	0.00	14024.52	14024.52	18569.22	32593.74
7	*Fraxinus floribunda*	0.00	15195.97	15195.97	10616.39	25812.36
8	*Celtis australis*	6780.38	2888.70	9669.08	14539.97	24209.05
9	*Alnus nepalensis*	6044.14	6048.56	12092.70	9049.47	21142.17
10	*Cassia fistula*	0.00	0.00	0.00	14100.90	14100.90
11	*Grevillea robusta*	0.00	0.00	0.00	13663.08	13663.08
12	*Thuja orientalis*	5252.10	628.00	5880.10	6919.95	12800.06
13	*Mangifera indica*	0.00	1283.15	1283.15	11367.58	12650.73
14	*Jacaranda mimosifolia*	0.00	0.00	0.00	10047.75	10047.75
15	*Callistemon citrinus*	0.00	2674.56	2674.56	6996.16	9670.72
16	*Juglans nigra*	0.00	4958.96	4958.96	4636.77	9595.73
17	*Araucaria columnaris*	0.00	4794.32	4794.32	2802.80	7597.12
18	*Choerospondias axillaris*	2000.91	0.00	2000.91	5570.79	7571.69
19	*Prunus cerasoides*	1411.48	0.00	1411.48	6112.71	7524.19
20	*Juniperus recurva*	3301.05	1744.45	5045.51	1851.27	6896.77

21	*Myrica esculenta*	0.00	2916.77	2916.77	3346.65	6263.43
22	*Homalium napaulense*	6199.86	0.00	6199.86	35.07	6234.93
23	*Melia azedarch*	0.00	0.00	0.00	6182.76	6182.76
24	*Salix tetrasperma*	0.00	0.00	0.00	5747.06	5747.06
25	*Pyrus pyrifolia*	0.00	0.00	0.00	4527.58	4527.58
26	*Araucaria heterophylla*	0.00	2893.51	2893.51	1453.27	4346.78
27	*Lagerstroemia indica*	0.00	0.00	0.00	3592.83	3592.83
28	*Pyrus malus*	0.00	0.00	0.00	2652.63	2652.63
29	*Litchi chinensis*	0.00	0.00	0.00	2421.60	2421.60
30	*Prunus persica*	0.00	0.00	0.00	2134.46	2134.46
31	*Populus jacquemontiana*	0.00	0.00	0.00	2028.17	2028.17
32	*Ficus elastica*	0.00	0.00	0.00	1598.28	1598.28
33	*Juglans regia*	0.00	954.20	954.20	495.06	1449.26
34	*Ilex excelsa*	0.00	0.00	0.00	1304.13	1304.13
35	*Borassus flabellifer*	0.00	0.00	0.00	1282.70	1282.70
36	*Prunus domestica*	0.00	0.00	0.00	1277.13	1277.13
37	*Nyctanthes arbor-tristis*	0.00	0.00	0.00	1132.92	1132.92
38	*Ficus benghalensis*	0.00	0.00	0.00	1117.54	1117.54
39	*Persea duthiei*	0.00	0.00	0.00	1067.52	1067.52
40	*Bougainvillea glabra*	0.00	0.00	0.00	1065.18	1065.18
41	*Phoenix humilis*	0.00	0.00	0.00	1058.54	1058.54
42	*Phyllanths emblica*	0.00	0.00	0.00	619.48	619.48
43	*Juniperus indica*	0.00	0.00	0.00	473.45	473.45
44	*Psidium guajava*	0.00	0.00	0.00	444.45	444.45
45	*Diospiros kaki*	0.00	0.00	0.00	414.54	414.54

46	*Pyrus pashia*	0.00	0.00	0.00	322.64	322.64
47	*Persea Americana*	0.00	0.00	0.00	305.10	305.10
48	*Madhuca longofolia*	0.00	0.00	0.00	280.04	280.04
49	*Sambucus hookeri*	0.00	0.00	0.00	243.11	243.11
50	*Erythrina stricta*	0.00	0.00	0.00	232.33	232.33
51	*Citrus maxima*	0.00	0.00	0.00	229.85	229.85
52	*Ficus neriifolia*	0.00	0.00	0.00	218.45	218.45
53	*Bauhinia variegate*	0.00	0.00	0.00	185.18	185.18
54	*Manglietia insignis*	0.00	0.00	0.00	167.68	167.68
55	*Elaeocarpus sphaericus*	0.00	0.00	0.00	166.31	166.31
56	*Thespesia lampas*	0.00	0.00	0.00	158.67	158.67
57	*Juniperus chinensis*	0.00	0.00	0.00	158.51	158.51
58	*Ficus auriculata*	0.00	0.00	0.00	129.05	129.05
59	*Michelia fuscata*	0.00	0.00	0.00	122.79	122.79
60	*Buddleja asiatica*	0.00	0.00	0.00	78.12	78.12
61	*Punica granatum*	0.00	0.00	0.00	75.58	75.58
62	*Berberis asiatica*	0.00	0.00	0.00	47.56	47.56
63	*Malvaviscus arboreus*	0.00	0.00	0.00	45.44	45.44
64	*Rhododendron arboreum*	0.00	0.00	0.00	36.33	36.33
65	*Hibiscus rosa-sinensis*	0.00	0.00	0.00	36.24	36.24
66	*Schefflera impress*	0.00	0.00	0.00	31.76	31.76
67	*Citrus jambhiri*	0.00	0.00	0.00	28.27	28.27
68	*Citrus limon*	0.00	0.00	0.00	27.78	27.78
69	*Magnolia soulangeana*	0.00	0.00	0.00	26.41	26.41

70	*Euphorbia pulcherrima*	0.00	0.00	0.00	23.43	23.43
71	*Ligustrum confusum*	0.00	0.00	0.00	20.98	20.98
72	*Ficus semicordata*	0.00	0.00	0.00	20.49	20.49
73	*Hibiscus brackenridgei*	0.00	0.00	0.00	13.40	13.40
74	*Albizia julibrissin*	0.00	0.00	0.00	9.67	9.67
75	*Jasminum mesneyi*	0.00	0.00	0.00	8.62	8.62
76	*Citrus aurantifolia*	0.00	0.00	0.00	8.20	8.20
77	*Alstonia neriifolia*	0.00	0.00	0.00	7.96	7.96
78	*Cotinus coggygria*	0.00	0.00	0.00	7.39	7.39
79	*Syzigium cumini*	0.00	0.00	0.00	7.28	7.28
80	*Michelia champaka*	0.00	0.00	0.00	6.55	6.55
81	*Ricinus communis*	0.00	0.00	0.00	5.50	5.50
82	*Camellia japonica*	0.00	0.00	0.00	5.47	5.47
83	*Cyphomandra betaceae*	0.00	0.00	0.00	2.18	2.18
84	*Carica papaya*	0.00	0.00	0.00	1.94	1.94
85	*Bambusa nepalensis*					5077.39
	Total	**789871.48**	**80538.80**	**870410.27**	**380302.94**	**1255790.61**

Appendix IX: Conference participation

Paper presentation

International

1 Shrestha, B., Sharma, B. K., & Yadav, R. K. P. (2017). "*Monitoring species diversity in trees outside forests of urban and suburban areas of Kathmandu district, Nepal*". Paper presented in International Conference on Biodiversity, Climate Change Assessment and Impacts on Livelihood organized by PL: USAID-IPM-IL-Biodiversity Project, Kathmandu, Nepal.

2 Shrestha, B., Sharma, B. K., & Yadav, R. K. P. (2018). "*Trees Outside Forests in Kathmandu Valley, Nepal*". Paper presented in International Symposium on Life: The 1st Forest Products Culture Research Group Colloquium" organized by World Wood Day Foundation, Siem Reap, Cambodia.

3. Shrestha, B., Sharma, B. K., & Yadav, R. K. P. (2022). "*Assessment of Micro-habitats on Trees outside Forest in Kathmandu Valley*". Paper presented in International Conference on "Biodiversity and Bioprospecting" organized by Department of Plant Resources (DPR), Kathmandu, Nepal.

National

1. Shrestha, B., Sharma, B. K., Baniya, C. Bd., & Yadav, R. K. (2020). "*Estimation of phyto carbon stock in Trees outside Forests in Kathmandu valley, Nepal*". Paper presented in National Conference on Integrating Biological Resources for Prosperity organized by Nepal Biological Society, Biratnagar, Nepal.
2. Shrestha, B., Sharma, B. K., & Yadav, R. K. P. (2022). "*Importance of Trees outside Forest for Fruit Yield*". Paper presented in National Conference on Science for Society and Innovation for Prosperity organized by Nepal Academy of Science and Technology, Kathmandu, Nepal.

Poster presentation

International

Shrestha, B., Sharma, B. K., & Yadav, R. K. (2016). "Assessment of Trees Outside Forests in Kathmandu Valley, Nepal". International symposium organized by World

Wood Day Foundation on Nature and Culture: Interdisciplinary Approaches to Peaceful Coexistence and Sustainable Development. Kathmandu, Nepal.

National

Shrestha, B., Sharma, B. K., & Yadav, R. K. (2016). "Assessment of Trees Outside Forests in Kathmandu Valley, Nepal". National conference organized by Nepal Academy of Science and Technology on Science, Technology and Innovation for Nepal's Graduation to Developing Country Status. Kathmandu, Nepal.

Appendix X: Scientific Publications (Main papers)

This Ph. D. thesis has four main papers.

1. **Shrestha, B.,** Sharma, B. K., & Yadav, R. K. P. (2022). Valuation of timber and firewood of trees outside forest along the urban–rural gradient in Kathmandu valley, Nepal. *Banko Janakari*, **32**(2), 19–36. *https://doi.org/10.3126/banko.v32i2.50894* (attached herewith)
2. **Shrestha, B.,** Sharma, B. K., and Yadav, R. K. P. (2022). Tree-related Microhabitats and Trees Outside Forest along the Urban-Rural Gradient in Kathmandu Valley. *Journal of Plant Resources - Special Issue*, **20**(2), 12-28. https://doi.org/10.3126/bdpr.v20i2.56949. (attached herewith)
3. **Shrestha, B.,** Sharma, B. K., Baniya, C. B., and Yadav, R. K. P. (2023). Assessment of tree species richness and phytomass carbon stock along the urban-rural gradient in trees outside forests of Kathmandu Valley, Nepal. *Arboricultural Journal*, 1-21. https://doi.org/10.1080/03071375.2023.2241812 . (attached herewith)
4. **Shrestha, B.,** Sharma, B. K., Baniya, C. B., and Yadav, R. K. P. (Unpublished manuscript). Assessment of species diversity and phytosociological parameters of trees outside forests along urban–rural gradient in Katmandu Valley, Nepal.

Appendix XI: Courses attended during Ph. D.

1 Workshop on "Research Methodology" organized by Central Department of Botany, TU, Kathmandu, Nepal. June 8-13, 2014.

2 Training on "Research Methodology for Ph. D. Scholars" organized by Central Department of Botany, TU, Kathmandu, Nepal. June 20-26, 2017.

3 Training on "Data Management and Analysis Workshop" organized by Gramin Adarsha Multiple Campus, Nepaltar, Kathmandu, Nepal, June 16-22, 2019.

4 Workshop on "Scientific Literature Review, Research Methodology and Academic Writing" organized by Central Department of Botany, TU, Kathmandu, Nepal. November 24-26, 2019.

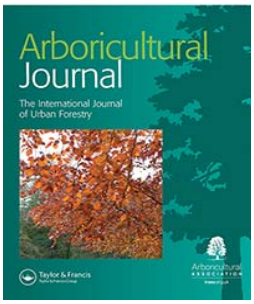
5 Webinar on "Staying well during your Ph. D., postdoc or research career Confirmation" organized by Digital Health CRC Education Dec 12, 2019.

6 Webinar organized by Digital Health CRC Education on (a) It's a Ph. D. not a Nobel Prize': What are Ph. D. examiners thinking? (b) Creating a structure for your Literature review part-1 and part-2. (c) 7 ways the Research Design canvas can help you plan, progress and finish your Ph. D. Confirmation, June 30, 2020.

7 Virtual training program on "Data management and visualization with R" Mr. Mohan Pudasaini, Statistics Officer, Government of Nepal, July 13 – 17, 2020.

8 Orientation program organized by TU Central Library on Remote access of Pre-Quest Database. 2078/1/10. (Online)

9 Capacity development training on "Data Management and Analysis in Biological Research" organized by the Department of Zoology, Patan M. Campus, Lalitpur. Asadh 22-24, 2079.



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Tree species richness and phytomass carbon stock along the urban-rural gradient in trees outside forests of Kathmandu valley, Nepal

Babita Shrestha, Bhuvan Keshar Sharma, Chitra Bahadur Baniya & Ram Kailash Prasad Yadav

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Tree species richness and phytomass carbon stock along the urban-rural gradient in trees outside forests of Kathmandu valley, Nepal

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ABSTRACT

Trees outside forests (TOF) are woody plants found on land which is less than 0.5 ha. These are important for biodiversity conservation and carbon storage. This study was conducted in Kathmandu Valley, central Nepal to determine tree species diversity and phytomass carbon stock patterns along the urban to rural spatial gradient of TOF. A detailed inventory was conducted across a total of 209 randomly selected points generated by MS Excel using circular plots of 20 m radius each. A total of 6,210 trees from 150 species belonging to 111 genera and 57 families were recorded under three strata (urban, suburban and rural). Out of 150 species, 53.33% were native and 46.67% were exotic. The average tree density was found to be higher in the suburban stratum (248.44 ha^{-1}) compared to the urban (232.58 ha^{-1}) and the rural (224.88 ha^{-1}) strata. Species richness was found to be higher in the rural stratum (14.09 ha^{-1}) compared to the urban (9.85 ha^{-1}) and the suburban (9.70 ha^{-1}) strata. But average species richness was found to be highest in the urban stratum (55.95 ha^{-1}) followed by the suburban (46.31 ha^{-1}) and the rural (45.74 ha^{-1}) strata, respectively. Similarly, the average phytomass carbon stock recorded was highest in the urban stratum (39.41 t ha^{-1}) compared to the rural (29.19 t ha^{-1}) and the suburban (26.06 t ha^{-1}) strata. The average phytomass carbon stock varied significantly between the native and the exotic species only in the urban stratum but not in the suburban and the rural strata. This study provides baseline data useful for green urban planning and development as well as carbon sink management.

ARTICLE HISTORY
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KEYWORDS
Diversity; exotic species; native species; phytomass carbon; species richness

Introduction

The Food and Agriculture Organization (FAO, 1998) defines trees outside forests (hereafter TOF) as "the plants on the land that fulfils the requirements of forest and other wooded land except that the area is less than 0.5 ha and the canopy is < 10%; scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconut; trees in park and gardens, around buildings and in

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lines along streets, roads, railways, rivers, streams and canals; trees in shelterbelts of less than 20 m width and 0.5 ha area". TOF comprises trees ranging from a single discrete individual tree to systematically managed trees (Kleinn, 2000). TOF includes both trees as well as shrubs (Foresta et al., 2013). TOF may vary from predominantly natural growths such as woodlots, gallery forests and riparian buffers to cultivated areas in farmlands, around lakes, in towns, or in small aggregates such as clumps of trees, scattered woods, urban parks, etc (Bellefontaine et al., 2002).

TOF offers a win–win land use strategy for climate change mitigation and adaptation through a range of ecological and socio-economic functions such as carbon sequestration and other environmental services (Nair, 2011; Plieninger, 2011; Skole et al., 2021). These benefits have made it necessary for governmental bodies and other stakeholders including international organisations to require detailed information on TOF.

Due to urbanisation, more than half of the world's population now live in urban areas, which is predicted to continue to grow at 4% a decade by 2050 (UN, 2015). It is believed that urbanisation is one of the major causes of the loss of plant diversity at local and regional levels. The pattern of plant diversity along the urban – rural gradient or urbanisation degree is not very clear (Wang et al., 2020). An urban – rural gradient can be used to examine changes in plant species composition related to human-altered habitats. Generally, species richness and the Shannon Wiener Diversity Index increase from the urban to rural gradient (Vakhlamova et al., 2014). Urban green spaces compared to rural areas, are usually dominated by artificial vegetation (Wang et al., 2020). Due to large-sized trees and higher tree density out of five carbon pools, carbon stored in the above-ground tree biomass is the largest in forests (Intergovernmental Panel on Climate Change [IPCC], 2006; Tang et al., 2016). Though the carbon stock density of TOF in the urban green areas is smaller than that of forests, there is the potential for considerably higher storage capacity (Matasov et al., 2020). Trees play a significant role in biodiversity conservation, provide natural greenery and act as a carbon sink. Agro-forestry, urban forestry, etc. are some options which can be used to overcome the hazards of deforestation. Urban TOF helps to maintain urban greenery (Chaudhry, 2011).

There were many trees in Kathmandu Valley, Bagmati province in Nepal, in the past (Sharma, 2021) along roadsides, crossroads or near temples. Many of the common areas where trees were present belonged to government or local co-operatives or guthis (Sharma, 2021). The first organised tree planting was started in the Malla Era and continued up to the Rana Era (Poudel, 2010). During those times, paved paths were expanded and extended, and trees were planted on both sides of the path. The government adopted urban planning concepts influenced by Western Europe by planting more trees. New species like *Araucaria araucana*, imported from Europe along with pines were planted to beautify Kathmandu Valley's urban areas and palaces. With the introduction of modern urban-environmental planning in the 1960s and 1970s, the government renovated roads and trails throughout Kathmandu. In the 1980s, urban environmental planners introduced a three-line green belt. Trees were also planted along either side of other roads (Poudel, 2010), roadside gardens and traffic islands (Baral & Kurmi, 2005). Many parks were also built during different historical eras as were a botanical garden and zoo. Thus, many native as well as exotic tree species were planted, which helped to improve biodiversity, aesthetic value, urban greenery and carbon storage.

In the current time period, migration has rapidly expanded the boundaries of urban Kathmandu (Chitrakar et al., 2014; Muzzini & Aparicio, 2013), leading to haphazard development of new settlements and neighbourhoods (International Centre for Integrated Mountain Development [ICIMOD], 2007). This has resulted in deforestation and forest fragmentation forming TOF. Despite the current awareness of the value of trees, TOF are less recognised as forest resources (Kleinn, 2000). Standing trees in urban areas have a great significance in terms of biodiversity conservation and urban greenery. Though the assessments of TOF have started in Nepal (Department of Forest Research and Survey [DFRS], Nepal, 2007), such assessments along the urban – rural gradient are sparse. Thus, this work has been undertaken to assess the patterns of TOF and to explain the relationship between tree species' diversity and phytomass carbon stock along the urban-rural gradient of Kathmandu Valley.

Materials and methods

Study area

The study was carried out in Kathmandu Valley (area ~66,500 ha) which includes the three districts: Kathmandu, Lalitpur and Bhaktapur of Bagmati Province in the middle hill region of central Nepal (Figure 1). This bowl-shaped Valley lies between 27°32′13″ N to 27°49′10″ N latitude and 85°11′31″ E to 85°31′38″ E longitude at an altitude of 1,300 metres above sea level. Kathmandu Valley is characterised by sub-tropical vegetation and a distinct monsoon climate with hot, wet summers and cold, dry winters (ICIMOD, 2007). The annual average temperature is 19.5°C and annual average rainfall is 1509 mm (Data between 2000 and 2018, Government of Nepal, Department of Hydrology and Meteorology [GoN, DHM], 2021) (Figure 2). The fluvial soil of Kathmandu Valley is believed to be highly fertile but nowadays has largely been built over with roads, buildings, commercial complexes, etc.

Methods

In order to survey all TOF in Kathmandu Valley, grids of 500 m × 500 m were prepared (n = 2800) across the entire study area (Figure 1) (Dida et al., 2016). A stratified random sampling technique was used to identify the locations of TOF in the grids. By visual interpretation of Google Earth images, 1,046 TOF sites were identified. These sites were categorised under the three strata urban, suburban and rural based on population size (Government of Nepal [GoN], 2014). Across the total identified TOF sites, 209 (20%) were randomly selected for sampling (Tang et al., 2016).) A map of the study area with sampling location points was prepared for each stratum using Google Maps (Figure 1). These sites were used to collect data for tree-level characteristics using circular plots with a 20 m radius (area = 0.13 ha) (Department of Forest Research and Survey [DFRS], Nepal, 2011). Tree-level characteristics of each woody plant with height >1.3 m and diameter at breast height (DBH) ≥ 5 cm were recorded. DBH was measured at 1.3 m above the ground using diameter tape and the tree height was assessed using a clinometer (Suunto PM-5/360 PC). Tree specimens not

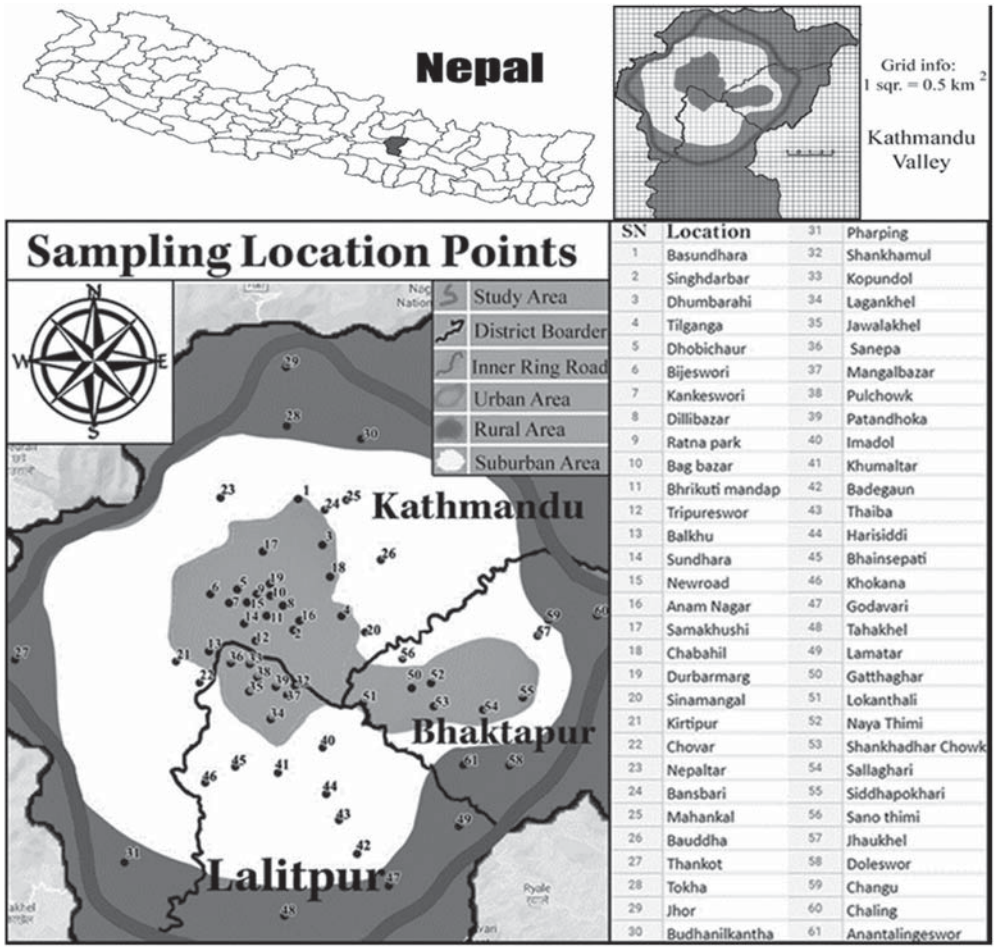

Figure 1. Map of the study area with sampling location points.

identified in the field were collected for herbarium preparation following standard procedure (Bridson & Forman, 1998) and identified in the Central Department of Botany, Tribhuvan University, Kathmandu. Press et al. (2000) was followed for plant nomenclature. Origin (Native/Exotic) of the species was based on Kew Science, Plants of the World Online.

Species richness of the study area and across the strata were estimated with respect to the area sampled at the study area and each stratum. Average species richness was calculated as the total number of species recorded per plot (Dorji et al., 2014). Importance Value Index (IVI) of species was calculated by following G. Mandal and Joshi (2014). Above ground tree biomass was calculated by using the following allometric equation given by Petersson et al. (2012):

$$\text{AGTB} = 0.0509\ \rho\ D^2\ H$$

Where, AGTB = above ground tree biomass (kg), ρ= wood-specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), H = tree height (m).

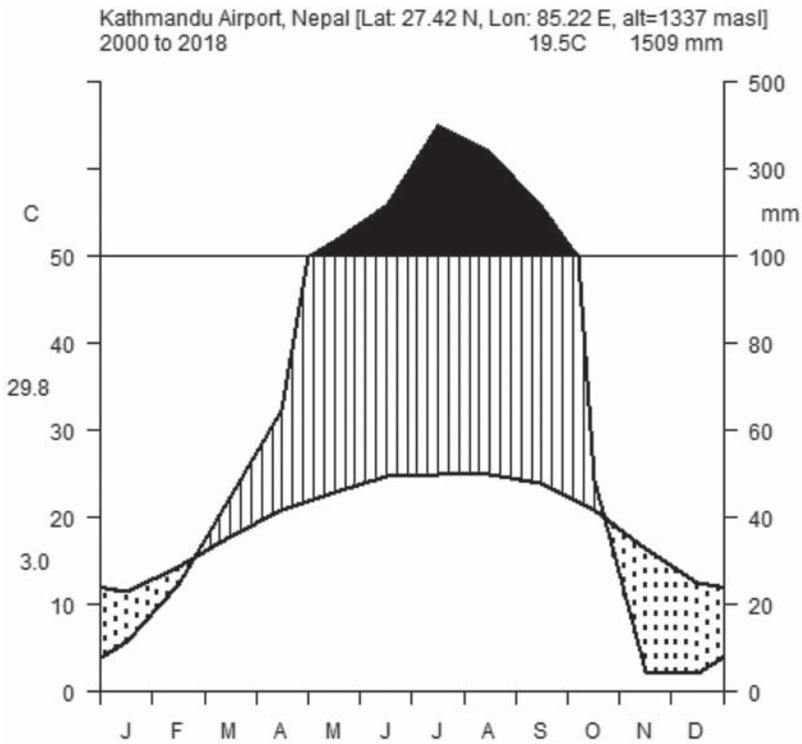

Figure 2. Average annual temperature and average annual rainfall of the study area. (Data between 2000–2018; GoN; DHM; airport station, 2021).

Wood specific gravity was used from the equation developed by E. R. Sharma and Pukkala (1990) and other published literature (B. K. Sharma et al., 2014; Zanne et al., 2009). Wood specific gravity values were not available for all species in the study area. For tree species with unknown wood-specific gravity, the arithmetic mean of all known tree species in the study area was substituted (Brown et al., 1989). Similarly, for shrub species with unknown wood-specific gravity, the arithmetic mean of all known shrub species in the study area was used. The biomass stock density (in kg m^{-2}) was calculated by summing up individual weights of a sampling area and dividing it by the total sampled area. The value was converted to ton ha^{-1} after multiplying it by 10 (Subedi et al., 2010). AGTB was then converted into phytomass carbon stock density by multiplying by 0.47 (IPCC, 2006). Root-to-shoot ratio value of 1:5 (20% of AGTB) was used to find below ground biomass (MacDicken, 1997). Total carbon stock density of trees of specific vegetation was calculated by summing up above ground and below ground tree carbon stock densities.

Statistical analysis

Prior to the statistical analyses, all data sets were checked for normality using the Shapiro – Wilk test ($p > 0.05$). Even after transformation, the data were not found to have a normal distribution, therefore, non-parametric methods were used. Variation in species richness, tree-related parameters, species origin and phytomass carbon across different strata were tested by the Kruskal-Wallis test followed by Mann–Whitney tests ($p < 0.05$) using statistical software PAST (Version 4.11). To understand the relationship between species richness and phytomass carbon over the entire study area, and considering the non-normal nature of the data, a non-parametric alternative of linear regression was used. Nonparametric regression is used to describe the trend between a response variable and one or more predictors. This is different from classical regression models in that it does not rely on strong assumptions regarding the shape of the relationship between the variables (Cizek & Sadıkoglu, 2020; Hazelton, 2015). The Kendall – Theil Sen Siegel nonparametric linear regression analysis is executed using *mblm* package in Rstudio (Mangiafico, 2016; Rstudio Team, 2022).

Results

Species richness and tree density

Altogether 150 species of TOF belonging to 111 genera and 57 families were enumerated from the study area (26.27 ha). The species number recorded varied from 1 to 21 with an average of 6.32 ± 3.60 (Table 1). Species richness was 5.71 ha^{-1}. Tree density varied from 15.91 ha^{-1} to 1217.05 ha^{-1} with an average of 236.35 ± 173.12 ha^{-1}. A larger number of species was recorded in the urban stratum (109) than in the suburban (89) and the rural strata (85) (Table 2). But species richness was found to be higher in the rural stratum (14.09 ha^{-1}) than in the urban (9.85 ha^{-1}) and the suburban (9.70 ha^{-1}) strata. The average number of species was found to be higher in the urban stratum (7.03 ± 3.98) compared with the suburban (5.82 ± 3.39) and the rural (5.75 ± 2.94) strata. The average species richness was found to be higher in the urban stratum (55.95 ± 31.67 ha^{-1}) than in the suburban (46.31 ± 26.99 ha^{-1}) and the rural (45.74 ± 23.35 ha^{-1}) strata. Of the total of 150 species in the study area, 80 (53.33%) were native and 70 (46.67%) were non-native or exotic (Appendix I). Higher proportions of native species were recorded in both the urban and the suburban strata whereas a higher proportion of

Table 1. Minimum, maximum and average values (±SD) of species number and tree density in the study area.

	Species number recorded	Tree density (ha^{-1})
Minimum	1	15.91
Maximum	21	1217.05
Average	6.32 ± 3.60	236.35 ± 173.12

Table 2. Number of plots, species number recorded with range, species richness (ha^{-1}) and average values (±SD, $n = 209$) in TOF in the strata. Similar letters across rows indicate no significant difference at $p \leq 0.05$ (Kruskal–Wallis test).

Strata	Total plots	Species number recorded with range	Species richness (ha^{-1})	Average species number	Average Species richness (ha^{-1})	Average tree density (ha^{-1})
Urban	88	109 (1–21)	9.85	7.03 ± 3.98 **a**	55.95 ± 31.67 **a**	232.58 ± 155.08 **a**
Suburban	73	89 (1–16)	9.70	5.82 ± 3.39 **a**	46.31 ± 26.99 **a**	248.44 ± 198.56 **a**
Rural	48	85 (2–15)	14.09	5.75 ± 2.94 **a**	45.74 ± 23.35 **a**	224.88 ± 165.31 **a**

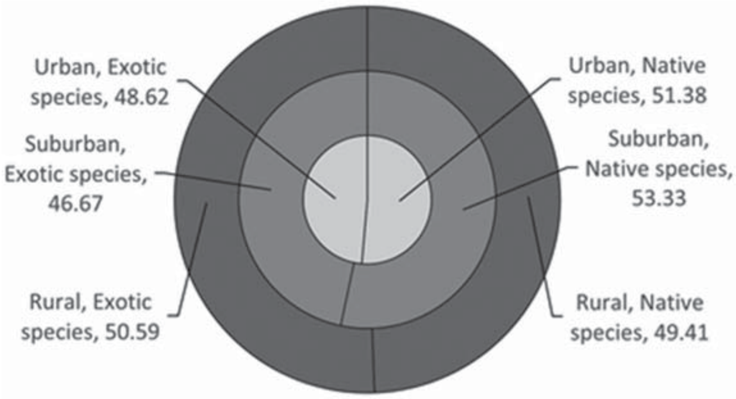

Figure 3. Pie chart showing percentages of native and exotic plant species across the strata.

exotic species was recorded in the rural stratum. In terms of percentage of native species, the suburban stratum was richer than the urban and the rural strata (Figure 3).

Similarly, the average tree density was found to be higher in the suburban stratum ($248.44 \pm 198.56\ ha^{-1}$) than in the urban ($232.58 \pm 155.08\ ha^{-1}$) and the rural ($224.88 \pm 165.31\ ha^{-1}$) strata. Species number, species richness and tree density did not show significant differences across strata as compared with their means (Kruskal-Wallis test, $p < 0.05$) (Table 2).

Importance value index (IVI)

Table 3 presents the IVI of tree species present in the study area. The five tree species with highest IVI values include *Grevillea robusta, Cinnamomum camphora, Thuja orientalis*, *Celtis australis* and *Pinus roxburghii*. *C. camphora* (IVI = 32.82), *G. robusta* (IVI = 27.51) and *T. orientalis* (IVI = 22.53) were the most important tree species in the urban stratum. *P. roxburghii* (IVI = 27.83), *G. robusta* (IVI = 18.51) and *T. orientalis* (IVI = 15.90) were the most important tree species in the suburban stratum. Similarly, *Bambusa nepalensis* (IVI = 30.97), *C. australis* (IVI = 22.71) and *C. camphora* (IVI = 18.77) were the most important tree species in the rural stratum.

Table 3. TOF species with their relative dominance, relative density, relative frequency and importance value index (IVI) in the study area. Number 1 to 5 – five highest dominating species and number 146 to 150 – five least dominating species.

SN	TOF species	Relative dominance	Relative density	Relative frequency	IVI
1	*Grevillea robusta* A. cunn. Ex R. Br.	47.76	5.51	4.43	57.71
2	*Cinnamomum camphora* (L.) J. Presl	6.30	7.12	6.10	19.53
3	*Thuja orientalis* L.	1.99	10.27	4.43	16.70
4	*Celtis australis* L.	3.99	3.97	4.58	12.54
5	*Pinus roxburghii Sarg.*	4.34	2.67	4.07	11.08
146	*Ginkgo biloba* L.	0.004	0.02	0.07	0.09
147	*Juniperus communis* L.	0.001	0.02	0.07	0.09
148	*Miliusa velutina* (Dunal) Hook.f. & Thombs	0.002	0.02	0.07	0.09
149	*Pyrus communis* L.	0.001	0.02	0.07	0.09
150	*Ricinus communis* L.	0.001	0.02	0.07	0.09

Tree height, DBH and phytomass carbon stock

In this study, the average height of trees varied from 1.63 to 20.37 m with an average of 7.28 ± 2.79 m whereas the average DBH varied from 6 to 100.55 cm with an average of 24.68 ± 13.79 cm (Table 4). Trees were not found to be very tall and very wide in some plots. The height of the tallest tree varied from 2 to 31.50 m with an average of 12.60 ± 5.24 m whilst the DBH of the widest tree varied from 7.2 to 203 cm with an average of 66.15 ± 35.17 cm. The average tree height and average DBH were found to be higher in the urban (8.15 ± 3.17 m and 25.55 ± 11.89 cm) than in either the suburban (7.01 ± 2.43 m and 24.07 ± 12.19 cm) or the rural (6.09 ± 1.99 m and 24.01 ± 18.72 cm) strata (Table 5). The average height of the tallest tree per plot was higher in the urban (14.82 ± 6.47 m) stratum than in the suburban (11.35 ± 3.60 m) and the rural (10.43 ± 2.84 m) strata whereas the average DBH of the widest tree was higher in the urban (72.46 ± 37.40 cm) compared to the rural (65.03 ± 40.50 cm) and the suburban (59.28 ± 26.70 cm) strata. The average height of trees and the average height of the tallest trees showed significant differences between urban-suburban and urban -rural strata but not between suburban-rural strata as compared with their means (Kruskal-Wallis test, $p \leq 0.05$). Average DBH of trees showed no significant differences across the strata. Similarly, the average DBH of the widest tree showed significant differences between the suburban-rural strata but no significant differences between the urban-suburban and urban-rural strata.

Phytomass carbon stock varied depending upon the height and width of the trees. The phytomass carbon stock varied from 0.23 t ha^{-1} to 299.56 t ha^{-1} with an average of 32.40 ± 38.44 t ha^{-1} (Table 4). Trees with the highest carbon stock were *C. camphora* (810.97 t ha^{-1}), *G. robusta* (680.78 t ha^{-1}) and *P. roxburghii* (593.63 t ha^{-1}) (Table 6). The average phytomass carbon stock was found to be highest in the urban stratum (39.41 ± 41.04 t ha^{-1}) (Table 5) where *G. robusta* (454.52 t ha^{-1}), *C. camphora* (451.49 t ha^{-1}) and *F. religeosa* (338.02 t ha^{-1}) were the highest carbon storing tree species. The average phytomass carbon stock in the suburban stratum was 26.06 ± 25.08 t ha^{-1} where *P. roxburghii* (243 t ha^{-1}), *Syzygium cumini* (234.39 t ha^{-1}) and *Eucalyptus camaldulensis*

Table 4. Minimum, maximum and average values (±SD) of height, DBH, tallest trees, widest trees and phytomass carbon stock in the study area.

	Average height (m)	Average DBH (cm)	Tallest tree (m)	Widest tree (cm)	Phytomass carbon stock (t ha^{-1})
Minimum	1.63	6	2	7.20	.23
Maximum	20.37	100.55	31.50	203	299.56
Average	7.28 ± 2.79	24.68 ± 13.79	12.60 ± 5.24	66.15 ± 35.17	32.40 ± 38.44

Table 5. Average values of height, DBH, height of tallest tree, DBH of widest tree, and phytomass C stock with (±SD) in three strata of the study area. Different letters across rows indicate significant difference at $p \leq 0.05$ (Kruskal–Wallis test).

Strata	Average height (m)	Average DBH (cm)	Average height of tallest tree (m)	Average DBH of widest tree (cm)	Average phytomass C stock (t ha^{-1})
Urban	8.15 ± 3.17 **a**	25.55 ± 11.89 **a**	14.82 ± 6.47 **a**	72.46 ± 37.40 **ab**	39.41 ± 41.04 **a**
Suburban	7.01 ± 2.43 **b**	24.07 ± 12.19 **a**	11.35 ± 3.60 **b**	59.28 ± 26.70 **a**	26.06 ± 25.08 **a**
Rural	6.09 ± 1.99 **b**	24.01 ± 18.72 **a**	10.43 ± 2.84 **b**	65.03 ± 40.50 **b**	29.19 ± 47.88 **b**

Table 6. Plant species, number of individuals and phytomass carbon stored in them in the study area. Number 1 to 5 with highest phytomass carbon stock and number 146 to 150 least phytomass carbon stock.

S.N.	Tree species	Number of individual trees	Phytomass carbon stock (t ha^{-1})
1	*Cinnamomum camphora* (L.) J. Presl	427	81.97
2	*Grevillea robusta* A. cunn. Ex R. Br.	373	68.78
3	*Pinus roxburghii* Sarg.	240	593.63
4	*Ficus religiosa* L.	159	541.96
5	*Populus jacquemontiana Dode.*	126	44.80
146	*Cyphomandra betaceae* (Cav.) Sendt	2	.02
147	*Jasminum mesnyi Hance*	3	.02
148	*Ricinus communis* L.	1	.02
149	*Vitex negundo* L.	1	.012
150	*Eriobotrya japonica* (Thumb.) Lindl.	1	.008

(187.74 t ha^{-1}) were the highest carbon storing tree species. Similarly, the average phytomass carbon stock in the rural stratum was 29.19 ± 47.88 t ha^{-1} where *C. camphora* (267.33 t ha^{-1}), *E. camaldulensis* (179.90 t ha^{-1}) and *Schima wallichii* (136.83 t ha^{-1}) were the highest carbon storing tree species. The average phytomass carbon stock showed significant differences between urban-rural and suburban-rural strata but not between urban-suburban strata (Kruskal–Wallis test, $p \leq 0.05$) (Table 5).

Although the average phytomass carbon stock was found to be more in the exotic species (16.24 ± 26.70 t ha^{-1}) than in the native species (16.16 ± 28.30 t ha^{-1}) in the study area, they did not differ significantly (Mann–Whitney test, $p > 0.05$). The average phytomass carbon stock was significantly higher in the native species only in the urban stratum but that did not vary in the suburban and the rural strata (Table 7). Moreover, the average phytomass carbon stock showed no significant variation in native species across strata whilst it showed significant variation in the exotic species across strata. The average phytomass carbon stock was found to be higher in the exotic species in the urban stratum than those in the suburban and the rural strata.

The Kendall – Theil Sen Siegel nonparametric linear regression analysis was used to examine the relationship between phytomass carbon (t ha^{-1}) and species richness and showed a significant positive linear relationship (Figure 4). The analysis does not return the R^2 values. However, the intercept was 14.35 ($p < 0.001$) and slope for species richness was 0.34 ($p < 0.01$).

Table 7. Variation of phytomass carbon stock in native and exotic species in a stratum and across three strata in the study area. Different letters across rows indicate significant differences (Mann–Whitney test and Kruskal–Wallis ANOVA).

	Strata			
Species Origin	Urban	Suburban	Rural	
Native	20.64 ± 36.29	14.06 ± 21.35	11.16 ± 18.40	p > 0.05
Exotic	18.77 ± 20.99**a**	12.00 ± 14.46**b**	18.03 ± 44.45**bc**	p < 0.01
	p < 0.01	p > 0.05	p > 0.05	

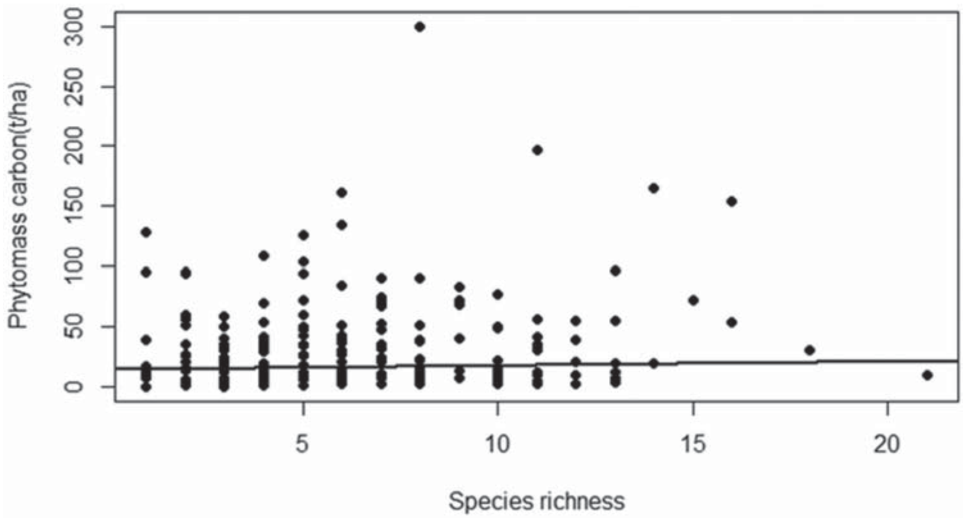

Figure 4. Relationship between species richness and phytomass carbon stock in the study area.

Discussion

The number of TOF species in the study area is lower than that of the Mid-hills Mountain Forests (1147) (Department of Forest Research and Survey [DFRS], Nepal, 2015) but comparatively higher than that of the Bajrabarahi Sacred Grove (18) and Pashupati Sacred Grove (17) in the same study area (Shrestha et al., 2015). The variation of the number of species per plot (Schmitt-Harsh et al., 2013) is approximately similar to our study. Species diversity depends upon the land use and the enumeration method. Tang et al. (2016); Lamichhane et al. (2010); Kumar (2011); Kharal and Oli (2009); and Oli et al. (2015) found lower numbers because these studies were carried out only on street trees, home gardens and farmlands. Similarly, Baral et al. (2013) also found lower numbers of species in home gardens, roadside plantations, silvopasture (private plantations) and agri-silviculture respectively. Enumerating all vascular plants, Cornelis and Hermy (2004) and Wang et al. (2020) recorded more species and generic diversity in urban and suburban parks in Flanders, Belgium and in Shanghai, China, respectively. The study of only hedges by Thompson et al. (2010) found fewer species in the urban and suburban gardens in Khartoum, Sudan. Vakhlamova et al. (2014) reported a slightly higher total number of species in the urban – rural gradient in Kazakhstan due to the enumeration of all vascular plants, where they also found an increasing trend in species richness from urban to rural areas. The general trend of species richness shows that it declines linearly from rural areas to urban ones (Ranta & Viljanen, 2011). We also find this trend in our study where species richness per hectare was higher in the rural stratum than in the urban and the suburban strata. But our study showed a higher total number of species in the urban stratum followed by the suburban and the rural strata. This is because planted trees are found in larger numbers in offices, schools, colleges, home gardens, parks, museums, roads etc. Wang et al. (2020) and Schwoertzig et al. (2016) found similar results to our study: showing an increasing trend of the number of species with increasing urbanisation. However, Ranta and Viljanen (2011) found a suburban peak of species richness, i.e. highest species richness in the suburban areas in the city of Tampere, Finland. This is due to the homogeneity of coniferous trees in the rural areas of Finland.

The number of the native species in the present study was higher than the exotic species in the study area except for the rural stratum where there were more exotic species recorded. Endale et al. (2016); Tramme et al. (2020); Kehlenbeck et al. (2011) also found more native species in urban forests, but Koricho et al. (2020); Mologni et al. (2021) recorded more exotic species. The number of native species increased from the urban to the suburban strata but declined in the rural stratum in the present study. Vakhlamova et al. (2014), on the other hand, reported an increasing number of native species from the urban to the rural areas in Kazakhstan. This is due to a relatively short period of urban development in Kazakhstan.

Although a higher tree density was found in the suburban stratum in the present study, there was no significant variation across the strata. TOF density was less in Nawalparasi district where the urban stratum had a higher tree density than the rural (Kharal et al., 2008). Low TOF density was also apparent in the Morang District where the urban stratum had a higher tree density compared to the rural areas (DFRS, 2007). This may be due to the methodology of only counting trees with DBH >10 cm. The average tree density was recorded to be much higher in Dhaka, Bangladesh (Jaman et al., 2020) due to the enumeration of all the plants, regardless of minimum DBH requirements. However, the average tree density and species number were less in Southern Kerala, India (Kunhamu et al., 2015) because this study included only trees in large, medium and small peri-urban home gardens. The variation of tree density per plot was higher in private residential urban forest structures where all plants with ≥2.5 cm DBH were enumerated (Schmitt-Harsh et al., 2013).

The dominance of tree species and their importance varies in different areas and land uses. *G. robusta* was found in abundance on the streets and was the most dominant species of the entire study area. Due to plantation for use as timber, *Tectona grandis* had higher IVI in agroforestry systems in Andongrejo Village, Jember Regency, East Java (Hartoyo et al., 2020). Only enumerating trees with >10 cm DBH, G. Mandal and Joshi (2014) found a higher IVI of *S. robusta* in the forests of the Selaquie Jhajra range, Thano range and Asarori range respectively in Doon Valley, Western Himalaya, India. Similarly, Maharjan et al. (2016–18) in the Baghmara Buffer Zone Community Forest, Chitwan, Nepal and Rawal and Subedi (2022) in the community-managed forest of the Mid-Western Hilly Region, Nepal found high IVI values. This might be due to enumeration of all trees regardless of DBH in the study. With the same DBH criteria, Giriraj et al. (2008) in the tropical wet evergreen forests of the western ghats, India and Ajayi and Obi (2016) in Cross River National Park, Nigeria reported lower IVI values. In our study, the dominant species were *C. camphora*, *P. roxburghii* and *B. nepalensis* in the urban, the suburban and the rural strata respectively. Such variations within the study area were due to planting of *C. camphora* on the streets by the Government and other organisations in the urban stratum; plantations of *P. roxburghii* along the roads and woodlots in the suburban stratum; and planting and natural vegetation of *B. nepalensis* in the rural stratum. The dominant tree species types and IVI were different in the Sacred Groves in the study area. *Neolitsea cuipala* was the dominant tree species with higher IVI in a single forest type in the Bajrabarahi Sacred Grove while *S. wallichii*, *Rapanea capitellata* and *Quercus* *glauca* were the most dominant tree species with higher IVI in three forest types respectively in Pashupati Sacred Grove in the study area (Shrestha et al., 2015). Similarly, Chhetri and Shrestha (2019) reported higher values of IVI in *Eurya acuminate* in the lower temperate zone, *Lithocarpus pachyphylla* in the middle temperate forest and *Lithocarpus pachyphylla* in the upper temperate forest. This might be due to the enumeration of all vascular plants with ≥10 cm DBH only. Similarly, in the study of tree/shrub species on farms in North-eastern Ethiopia, Muche et al. (2022) found low dominancy of *Acacia seyal* at low and mid-altitude plots and *Eucalyptus globulus* in the highlands, respectively.

When compared to our study, the average TOF height (9 m) was higher, but the average DBH (24 cm) was similar as reported in Nawalparasi District, Nepal (Kharal et al., 2008). This is due to the dominance of *Dalbegia sissoo*, *Mangifera indica*, *Melia azedarach* in Nawalparasi. Conversely, both the average TOF height (6 m) and the average DBH (20 cm) were lower in Morang district, Nepal (DFRS, 2007). This is due to the dominance of *D. sissoo*, *Albizziz indica*, *Saraca indica* there. Similarly, average tree height and DBH in the street trees in the Pokhara and the Bharatpur Districts of Nepal were high (Lamichhane et al., 2010). The frequency of *D. sissoo*, *S. indica, C. camphora* and *M. azedarach* were higher in both the Pokhara and the Bharatpur. Due to enumeration of trees in fenced areas only, tree height range was lower in the urban and peri-urban gardens of Khartoum, Sudan (Thompson et al., 2010). As the trees were not very mature, the mean DBH values were lower in urban parks and the playground edge plantations (Jaman et al., 2020). Maturity of the trees is also affected by the management of the land. Mean DBH values were lower in fuelwood harvesting sites than in reference sites (Nerfa & Rhemtulla, 2019). The average tree height and DBH were found higher in the Bajrabarahi Sacred Grove and the Pashupati Sacred Grove in Kathmandu Valley (Shrestha et al., 2015).

There were variations in phytomass carbon, with the urban stratum showing highest values in the present study. The value of phytomass carbon stock differs depending upon differences in land use. Due to the calculation of above ground carbon only on farms, the mean values of phytomass carbon of three different altitudinal zones in the upland, midland and lowland zones in Mount Kilimanjaro, Tanzania (Mathew et al., 2016) were lower than our findings. Mean phytomass carbon stock in coffee agroforestry in eastern Ethiopia (Toru & Kibret, 2019), in TOF along roads and agroforestry in the semi-arid region of southern Haryana (Singh & Chand, 2012) were lower; tree density was also lower. Similarly, Baral et al. (2013) also reported less phytomass carbon in residential gardens, roadside plantations and agri-silviculture, respectively, in Kanchanpur District. In contrast, residential gardens in Cooch Behar, Jalpaiguri and Siliguri, West Bengal with greater tree density showed comparatively higher average phytomass carbon stock (Subba et al., 2018). But R. A. Mandal et al. (2015) reported similar average phytomass carbon stock in rich and medium households in Sahodawa and Pipara, Mahottari District, Nepal. This is due to their higher tree density. Because of good management, reference sites had higher mean AGB than fuelwood harvesting sites (Nerfa & Rhemtulla, 2019). Due to higher numbers of species and undisturbed and mature sites, higher mean above-ground carbon stocks were observed in botanical gardens than in urban parks in Dhaka, Bangladesh (Jaman et al., 2020). The average phytomass carbon stock is higher in the Midhills Mountain Forests (82.13 t ha^{-1}) (DFRS,

2015) than of that in the study area. This is due to higher tree density and the higher number of species in the Midhills forests. Similarly, due to higher tree density, Shrestha et al. (2019) also found higher total average carbon stock for five forest types in the Pashupati Sacred Grove and the Bajrabarahi Sacred Grove. Due to the dominance of large-sized trees, species such as *Ginkgo biloba* and *Populus* sp., Tang et al. (2016) reported comparatively higher values of vegetation carbon storage in street trees in the urban districts of Beijing, China. The variation of Plant C-stock per parcel was lower in the urban forestry structures (Schmitt-Harsh et al., 2013). Similarly, Kleinn et al. (2015) reported lower average biomass stocks for TOF in Cameroon and the Philippines where Palm trees with DBH ≥10 cm were enumerated. In contrast, Guo et al. (2014) found high biomass carbon stocks in TOF in China in 2004–2008. However, this might be due to the assessment of different species of trees in woodlands, shrubberies and non-forest land in that study. Average C-stock was found to be comparatively lower in Molise region, Central Italy (Marchetti et al., 2018) but this may be due to the estimation of above ground average C-stock only. In the present study, the phytomass carbon stock had a significant positive relationship with species richness, which is consistent with the trend reported for the tropical hills of India (Pragasan, 2022), in a moderate-sized urban area in the Midwest, United States (Schmitt-Harsh et al., 2013) and Kanchanpur District, Nepal (Baral et al., 2013).

The average phytomass carbon stock was slightly higher in the exotic species in the study area. This might be due to the presence of larger sized exotic tree species such as *Araucaria*. A similar pattern was found in the rural stratum which might also be due to the presence of mature and larger sized exotic tree species such as *Araucaria*. In the case of the urban and suburban strata, average phytomass carbon stocks were found to be higher in the native species where such mature and larger sized exotic tree species such as *Araucaria* were less abundant.

Conclusion

The study reported 150 species and 111 genera belonging to 57 plant families in TOF in the Kathmandu Valley. Species richness was higher in the rural areas compared to the suburban and the urban areas. Moreover, tree density was higher in the suburban areas. Tree height and phytomass carbon stocks were highest in the urban areas compared to other strata. Although the number of species found in the study areas were less than those in the Middle Hill Mountain forests of Nepal, the observed diversity of tree species in these TOF play a significant role in biodiversity conservation, whilst also supplying subsistence materials to the urban-rural community. Additionally, while rapid urbanisation is said to be detrimental for biodiversity, the TOF of the urban stratum in Kathmandu Valley appear to be of great importance for carbon storage due to the higher average height and DBH of trees there. Native species are important contributing significantly to carbon storage compared to the exotic species in both urban and suburban strata but it is the reverse in the rural stratum in Kathmandu Valley. In addition, TOF also help to maintain urban greenery. The database of such assessments provides opportunities for framing significant policy or management decisions with regard to the relationship of carbon storage and species diversity.

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Author contributions

All authors contributed to concept development, research design, defining the intellectual content and literature research. B. Shrestha and B. K. Sharma collected the data. B. Shrestha, R. K. P. Yadav and C. B. Baniya analysed data and prepared the manuscript. R. K. P. Yadav and B. K. Sharma reviewed the manuscript.

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Appendix I. Plant species recorded in TOF in the study area. * Kew Science. Plants of the World online (N-Native, E-Exotic)

S.N.	Scientific name	Origin*
1	*Acacia catechu* (L.F.) Willd.	N
2	*Acacia nilotica* (L.) Willd. Ex Del.	N
3	*Acer oblongum* Wall. Ex DC.	N
4	*Agave cantula* Roxb.	E
5	*Alangium chinense* (Lour.) Harms	N
6	*Albizia julibrissin* Durazz.	N
7	*Albizia procera* (Roxb.) Benth.	N
8	*Alnus nepalensis* D. Don	N
9	*Alstonia neriifolia* D. Don	N
10	*Alstonia scholaris* (L.) R.Br.	N
11	*Anthocephalus chinensis* (Lam.) A. Rich. Ex Walp.	E
12	*Araucaria bidwillii* Hook.	E
13	*Araucaria columnaris* J. R. Forst & Hook.	E
14	*Araucaria heterophylla* (Salisb.) Franco	E
15	*Areca catechu* L.	E
16	*Artocarpus integra* (Thumb.) merr.	E
17	*Azadirachta indica* A. Juss.	E
18	*Bambusa nepalensis* Stapleton	N
19	*Bauhinia variegata* L.	N
20	*Berberis asiatica* Roxb. ex DC.	N
21	*Borassus flabellifer* L.	E
22	*Bougainvillea glabra* choisy	E
23	*Brugmansia arborea* Pers.	E
24	*Buchanania latifolia* Roxb.	N
25	*Buddleja asiatica* Lour.	N
26	*Burretiokentia vieillardii* Pic. Serm.	E
27	*Callistemon citrinus* (curtis) Skeels	E
28	*Camellia japonica* L.	E
29	*Carica papaya* L.	E
30	*Carya illinoensis* (Wangenheim) K. Koch	E
31	*Caryota urens* L.	E
32	*Cassia fistula* L.	N
33	*Cassia mimosaides* L.	N
34	*Casuarina equisetifolia* L.	E
35	*Cedrus deodara* (Roxb. ex D. Don) G. Don	N
36	*Celtis australis* L.	E
37	*Cestrum nocturnum* L.	E
38	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	N
39	*Cinnamomum camphora* (L.) J. Presl	E
40	*Cinnamomum tamala* (Buch-Ham)Nees & Eberm.	N
41	*Citrus aurantifolia* (Christm)Swingle	E
42	*Citrus jambhiri* Lush.	E
43	*Citrus limon* (L.) Burn. F.	E
44	*Citrus maxima* (Burm.) Herr.	E
45	*Citrus reticulata* Blanco.	E
46	*Cotinus coggygria* (Scop.)	N
47	*Croton roxburghii* Balakrishnan	E
48	*Cycus pectinata* Buch.-Ham.	N
49	*Cyphomandra betaceae* (Cav.) Sendtn.	E
50	*Dalbergia sissoo* Roxb.	N
51	*Diospyros kaki* Thunb.	E
52	*Diploknema butyracea* (Roxb.) Lam.	N
53	*Duranta erecta* L.	E
54	*Elaeocarpus sphaericus* (Gaertn.) K. Schum.	N
55	*Eriobotrya japonica* (Thumb.) Lindl.	E
56	*Erythrina arborescens* Roxb.	N
57	*Erythrina stricta* Roxb.	N
58	*Eucalyptus camaldulensis* Dehn.	E
59	*Euphorbia pulcherrima* Willd. Ex Klotzsch	E
60	*Ficus auriculata* Lour.	N
61	*Ficus benghalensis* L.	N

(*Continued*)

(Continued).

S.N.	Scientific name	Origin*
62	*Ficus benjamina* L.	N
63	*Ficus elastica* Roxb.	N
64	*Ficus lacor* Buch.-Ham.	N
65	*Ficus neriifolia* Sm.	N
66	*Ficus religiosa* L.	N
67	*Ficus semicordata* Buch- Ham ex Sm.	N
68	*Fraxinus floribunda* Wall.	N
69	*Ginkgo biloba* L.	N
70	*Gossypium arborium* L.	E
71	*Grevillea robusta* A. cunn. Ex R. Br.	E
72	*Hibiscus brackenridgei* A. Gray	E
73	*Hibiscus rosa-sinensis* L.	E
74	*Homalium napaulense* (DC.) Benth.	N
75	*Ilex excelsa* (Wall.) Hook. Fil.	N
76	*Jacaranda mimosifolia* D.Don	E
77	*Jasminum mesnyi* Hance	E
78	*Juglans nigra* L.	E
79	*Juglans regia* L.	E
80	*Juniperus chinensis* L.	E
81	*Juniperus communis* L.	N
82	*Juniperus indica* Bertol.	N
83	*Juniperus recurva* Buch.-Ham. ex D. Don	N
84	*Lagerstroemia indica* L.	N
85	*Lagerstroemia parviflora* Roxb.	N
86	*Lagerstroemia reginae* Roxb.	E
87	*Leucaena leucocephala* (Lam.) De Wit	E
88	*Ligustrum confusum* Decne.	N
89	*Lindera pulcherrima* (Nees) Benth. Ex Hook. F.	N
90	*Litchi chinensis* Sonner	E
91	*Litsea monopetala* (Roxb.) Pers.	N
92	*Macadamia integrifolia* Maiden & Betche	E
93	*Madhuca longofolia* (Koeing)	N
94	*Magnolia soulangeana* Soul.	E
95	*Mahonia nepaulensis DC.*	N
96	*Malvaviscus arboreus* Cav.	E
97	*Mangifera indica* L.	E
98	*Manglietia insignis* (Wall.) Blume	N
99	*Melia azedarach* L.	N
100	*Michelia champaka* L.	E
101	*Michelia fuscata* Bl.	E
102	*Miliusa velutina* (Dunal) Hook.f. & Thombs	N
103	*Morus alba* L.	E
104	*Murraya koenigii* (L.) Sprengel	N
105	*Musa paradisiaca* L.	E
106	*Myrica esculenta* Buch-Ham. Ex D. Don	N
107	*Myrsine capitellata* Wall.	N
108	*Nerium indicum* Miller	N
109	*Nerium oleander* variegatum	E
110	*Nyctanthes arbour-tristis* L.	N
111	*Persea americana* Mill.	E
112	*Persea duthiei* (King ex Hook. F.) Kosterm.	N
113	*Phoenix humilis* Royle.	N
114	*Phoenix sylvestris* Roxb.	N
115	*Phyllanths emblica* L.	E
116	*Pinus roxburghii* Sarg.	N
117	*Platanus orientalis* L.	E
118	*Podocarpus neriifolius* D. Don	N
119	*Populus jacquemontiana* Dode.	N
120	*Prunus avium* L.	E
121	*Prunus cerasoides* D. Don	N
122	*Prunus domestica* L.	E

(*Continued*)

(Continued).

S.N.	Scientific name	Origin*
123	*Prunus persica* (L.) Batsch	E
124	*Psidium guajava* L.	E
125	*Punica granatum* L.	E
126	*Pyrus communis* L.	E
127	*Pyrus crenata* Buch.- Ham. Ex D. Don.	N
128	*Pyrus malus* L.	E
129	*Pyrus pashia* Buch.-Ham. ex D. Don.	N
130	*Pyrus pyrifolia* (Burn.) Nak.	E
131	*Quercus glauca* Thumb.	N
132	*Rhododendron arboreum* Smith	N
133	*Ricinus communis* L.	E
134	*Salix tetrasperma* Roxb.	E
135	*Sambucus hookeri* Rehder	N
136	*Sapindus mukorossi* Gaertn.	N
137	*Schefflera impressa* (C. B. Clarke) Harms	N
138	*Schima wallichii* (DC.) Korth.	N
139	*Spathodea campanulata* P. Beauv	E
140	*Syzygium cumini* (L) Skeels	N
141	*Syzygium jambos* (L.) Alston	N
142	*Tecoma stans* (L.) H. B. K.	E
143	*Thespesia lampas* (Cav.) Dalz. & Gibs.	N
144	*Thuja orientalis* L.	E
145	*Toona ciliata* M. Roem.	N
146	*Trachycarpus* sp. H. Wendl.	N
147	*Vitex negundo* L.	N
148	*Woodfordia fruticosa* (L.) Kurz	N
149	*Zanthoxylum armatum* DC.	N
150	*Ziziphus incurva* Roxb.	N

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Tree-related Microhabitats and Trees Outside Forest along the Urban-Rural Gradient in Kathmandu Valley

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Abstract

Trees Outside Forests (TOF) are found in all strata as urban, suburban and rural. Some TOF serve as Tree Related Micro Habitats (TreMs). We conducted the assessment of TreMs on TOF in Kathmandu valley of central Nepal. Inventory was performed in 209 randomly selected points by Excel using circular plots with 20 m radius. Out of 6210 individuals of 150 tree species recorded from the study area, 1038 TOF of 64 species were found to serve as TreMs. 4 forms, 5 groups and 14 types of TreMs were recorded. Habitat types per tree varied from 1 to 6. 1, 2, 3, 4 and 5 habitat types were found in 665 (64.07 %), 293 (28.23 %), 67 (6.45 %), 8 (0.77 %) and 4 (0.38 %) trees respectively. 6 habitat types were found in one *Cinnamomum camphora* tree (0.10 %) with 8.60 m height and 75 cm DBH. Out of all the forms, groups and types, all were found in Urban TOF, one type (mistletoe) in suburban TOF and one form (fruiting bodies of saproxylic fungi and slime moulds) along with three types (mistletoe, invertebrate nest and sap run) were absent in rural TOF. The study explored the TreMs on TOF in Kathmandu valley. It provides the baseline data useful for micro habitats as well as biodiversity conservation.

Keywords: Cavity, Co-occurrence, Lichens, Nests, Orchids, Polypores

Introduction

Tree-related microhabitats (TreMs) are distinct structure present on trees that act as habitat for one or more species during at least a part of their life cycle to develop, feed, shelter or breed. Tree microhabitats are not born by all trees (Larrieu et al., 2018). The TreMs formation rate and number depends upon the size of the tree (Courbaud et al., 2021). Generally, invertebrates or vertebrates make habitat on trees (Larrieu et al., 2018). Number and types of microhabitats per tree vary depending upon the tree species and the maturity of the tree because this increase markedly with increased tree diameter. Therefore, very large trees are significant because they host almost all microhabitat types (Larrieu & Cabanettes, 2012). TreMs come under supporting ecosystem service (Bishop et al., 2010) which also help in biodiversity. Depending upon the landscape, frequency of occurrence of the microhabitat on either living or dead trees varies (Butler et al., 2020). Due to the limited life span, however, a new microhabitat can be formed after the death or decay of one type of microhabitat (Butler et al., 2021). Though TreMs are not the main indicator for species richness, they can be considered better than other established indicators (Magg et al., 2019; Noss, 1990). The new concept of TreMs as a surrogate biodiversity indicator is of special interest (Asbeck et al., 2021; Martin et al., 2022). There is a growing knowledge about TreMs by virtue of increasing research done in, especially forest ecosystems (Großmann et al., 2020; Regnery et al., 2013; Vuidot et al., 2011; Winter & Moller, 2008), yet all TreMs are not studied due to inconsistency in TreMs definitions in the available dataset. Furthermore, some TreMs are rarely recorded (Larrieu et al., 2021). But now experts have developed a typology of TreMs in forestry practice (Butler et al., 2021) as 7 forms, 15 groups and 47 types (Larrieu et al., 2018). The seven forms are - 1. Cavities, 2. Injuries expose sapwood, 3. Crown deadwood, 4. Excrescences, 5. Fungal fruiting bodies and slime moulds, 6. Epiphytic and epixylic structures and 7. Exudates.

Another aspect of TreMs is the co-occurrence patterns, which is poorly investigated. It is the co-dependency of more than one organism on the same tree. Tree species, DBH and state of the tree seem to be the crucial drivers of co-occurrence patterns (Courbaud et al., 2021; Larrieu & Cabanettes, 2012; Larrieu et al., 2014; Paillet et al., 2017). Though some TreMs such as dendrothelms (Kitching, 1971) or cavities (Wesołowski, 2007) have been well studied, several TreMs types are not studied yet, implying the existence of many knowledge gaps (Martin et al., 2022).

The retention of trees as TreMs in forests managed for timber production is essential for fulfilling the objectives of biodiversity conservation (Basile et al., 2020; Frey et al., 2020). Furthermore, biodiversity conservation should be done by keeping in mind the future of TreMs formation too (Courbaud et al., 2017; Courbaud et al., 2021). Study and assessment of these by providing guidelines to the concerned can play the important role for sustainable management of forest ecosystems regarding biodiversity conservation (Khanalizadeh et al., 2020; Martin et al., 2022).

Trees can be found in a wide range of patterns in human-influenced landscapes where ecological conditions are favorable to their growth (Bellefontaine et al., 2002). Trees Outside Forests (TOF) is one of them. Food and Agriculture Organization of the United Nations (FAO, 1998) defined TOF as "the plants on the land that fulfils the requirements of forest and other wood land except that the area is less than 0.5 ha, scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconut; trees in park and gardens, around buildings and in lines along streets, roads, railways, rivers, streams and canals; trees in shelterbelts of less than 20 m width and 0.5 ha area". TOF comprises both trees and shrubs, and tree ranging from a single discrete tree to systematically managed trees (Foresta et al., 2013; Kleinn, 2000). Nowadays, due to many issues, urban areas have expanded rapidly so as the inventory efforts of assessments of all the trees both within and outside forest areas across the urban–rural gradient (Westfall et al., 2018). Urbanization is one of the major causes for plant diversity loss at the local and regional scale (Wang et al., 2020). The urban-rural gradient explores the changes in plants from the rural area to the core urban (Ranta & Viljanen, 2011).

In the context of planted tree in Kathmandu Valley, King Jayasthithi Malla was the first recorded King to give order to plant trees alongside roads, water wells, in the divine domain and outer circle which was continued through the Rana period (Poudel, 2010). Rana Prime Minister Chandra Shamsher (1901-1929 A.D.) started a trend to plant the trees along Valley's roadsides and palaces. Trees were also planted along the highway from Kathmandu to Bhaktapur. Plantation of pipal (*Ficus religiosa*) trees in rural parts of the Valley is common to afford a convenient resting spots. In the 1980s, three-line tree planting was started forming a green belt around the Ring Road. But trees were continued to be felled for road expansion. Now the residents of Kathmandu Valley in association with civil society organizations and local governments are planting the trees even on the narrow pavements, resulted due to road expansion (Sharma, 2021).

Trees are important for the likelihood of future TreMs formations which helps in biodiversity conservation (Courbaud et al., 2021). TreMs assessments have been done in the developed countries. Though few researches have been done on species diversity, DBH class and volumes of TOF, TreMs on TOF is new to Nepal. Thus, to assess the TreMs abundance and richness on TOF along the urban-rural gradient in Kathmandu valley, this research had been done. This will provide the baseline data useful for micro habitat as well as biodiversity conservation.

Materials and Methods

Study area

The study was carried out in Kathmandu valley (area ~ 66,500 ha.) of Bagmati Province, situated in the middle hill region of central Nepal. It includes three districts Kathmandu, Lalitpur and Bhaktapur (Figure 1). It lies between 27°32'13'' N to 27°49'10'' N latitude and 85°11'31'' E to 85°31'38'' E longitude at an altitude of 1,300 m. The climate is of sub-tropical type and is influenced by distinct monsoon climate with hot, wet summers and cold, dry winters (International Centre for Integrated Mountain Development [ICIMOD], 2007). January and June are the coldest and hottest months with the annual average minimum and maximum temperatures as 3°C and 29.8°C respectively. Annual average rainfall is 1509 mm (data between 2000 – 2018) (GoN, DHM, airport station, 2021).

Site selection and sampling

A two-phase sampling strategy was applied for data collection (Lister et al., 2011). First phase included the listing up of TOF by aerial photos (image interpretation i.e., Google Earth) and second phase included the field survey. For this, grids of 500 m×500 m were prepared (n = 2800) in the entire study area (Figure 1) (Dida et al., 2016). Stratified random sampling method was used to identify the locations of TOF in the grids (Department of Forest, Research and Survey [DFRS], 2011). From visual interpretation of Google Earth Image, 1,046 TOF sites were identified under three strata as urban, suburban and rural on the basis of population (Central Bureau of Statistics [CBS], 2014) (Figure 1). Twenty percent of randomly selected by Excel of the total TOF sites identified (i.e., 209 sites) were used to collect data (Tang et al., 2016). A map of the study area with sampling location points was prepared (Figure 1). In the second phase data were collected using a circular plot with 20 m radius (area = 0.13 ha) (DFRS, 2011). Total area of 26.27 ha was studied in the study area. Tree level characteristics of woody plants with height > 1.3 m and diameter at breast height (DBH) ≥ 5 cm were recorded. DBH was measured at 1.3 m above the ground using diameter tape and the tree height was assessed using clinometer (Suunto PM-5/360 PC). Other organisms making one or more habitats or support on the TOF species were also enumerated. Nests and cavities if present were noted along with the organism types. Sap or resin if present was also recorded.

Identification of plants was done from herbarium specimen prepared following standard procedure (Bridson & Forman, 1998). The vernacular names

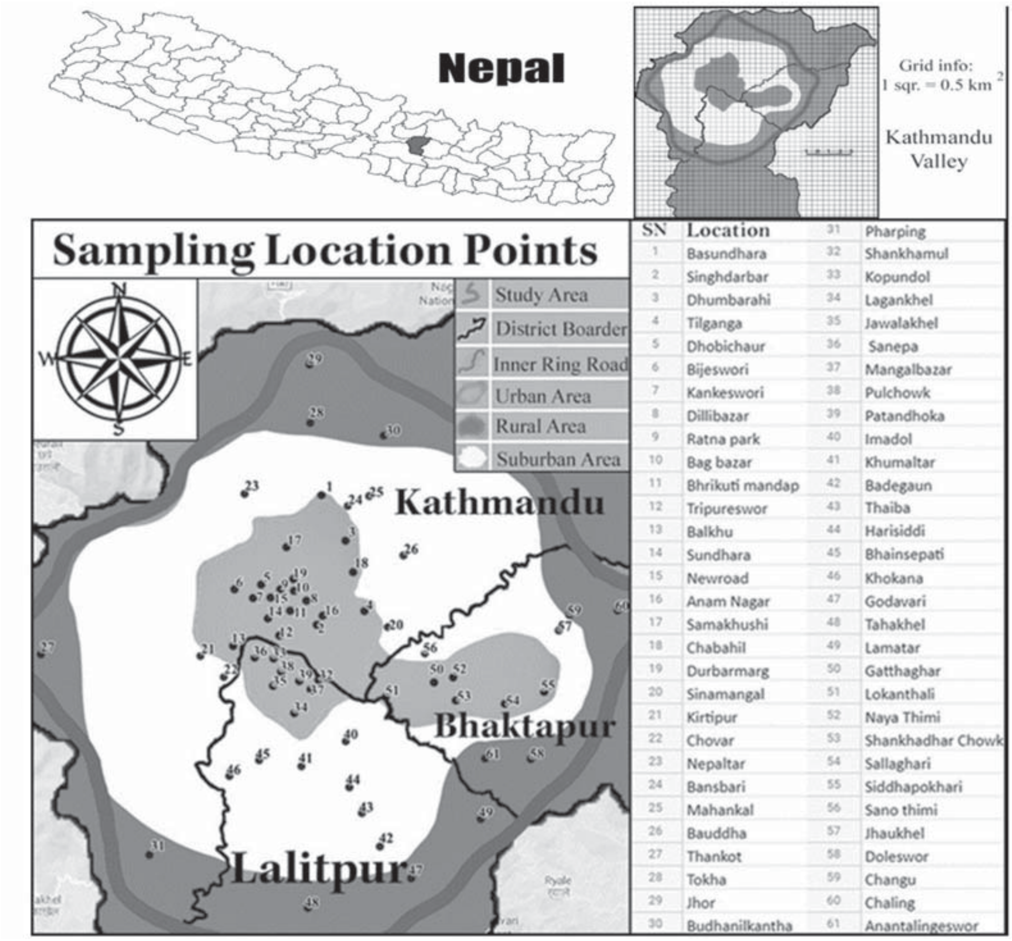

Figure 1: Map of the study area with sampling location points

were recorded with the help of local people and Sharma (2014). Scientific names were determined after identification by using literatures such as Flora of Kathmandu Valley (Malla et al., 1986), and after comparison with identified specimens previously deposited at Tribhuvan University Central Herbarium (TUCH), Nepal. Press et al. (2000), Shrestha et al. (2022) and Plants of the World Online (https://powo.science.kew.org/) were followed for plant nomenclature. The collected lichen samples were segregated according to their growth forms and further grouped according to the type of fruiting bodies. Then the lichen species was identified through morphological, anatomical studies with the help of micro and macro-lichens identification keys of Awasthi (2007), Baniya & Bhatta (2021) and Baniya et al. (2022). Fungi identification was done with the help of relevant Website (biodiversity library.org; Index fungorum; Jstor.org; Mycobank.org; Scircus; tropicos.org; Agaricus in the Pacific Northwest; Boletes in the Pacific Northwest) and Singer (1986). Similarly, orchids were identified through morphological studies with the help of Rokaya et al. (2013), Rajbhandari (2015) and Rajbhandari & Rai (2017).

Means and standard deviation of test variables were estimated following standard procedures. Variables related to TreMs were subjected to test of normality and were found not normal. Kruskal-Wallis tests were applied for multiple comparisons using SPSS (26).

Results and Discussion

In the study area

Trees Outside Forests (TOF) play an important role for the habitat conservation of ferns, mosses, lichens, fungi, and other phanerogams including orchids and parasitic plants. While TOF provide support to the climber plants, these are equally important for the habitat conservation of animals, insects and birds. In this study, a total of 6210 individuals (density = 236.35 ha^{-1}) of trees outside forests (TOF) with 150 species were recorded in the study area. Out of which 1038 individuals (density = 39.51 ha^{-1}) of TOF representing 64 species were found to serve as tree related microhabitats (TreMs) (Table 1) in 150 plots. After the enumeration of 2482 trees (>20 cm DBH), Winter and Moller (2008) found less number of microhabitat trees (571) in lowland beech forests in Germany. According to Khanalizadeh et al. (2020), microhabitats (272) were less of the five microhabitat types but individual trees (3382) were more in Oriental beech (*Fagus orientalis* L.) dominated forests in Iran. Both are due to enumeration of only the selected microhabitats. But in their international study of temperate and boreal forests from Northern Iran to Western Europe, Larrieu et al. (2021) found quite higher value as 70,958 individual trees of 78 tree species as TreMs in 2052 plots. Similarly, Piechnik et al. (2022) also observed the high number of TreMs density (46 ha^{-1}) in the Niepołomice Forest of S. Poland. It was due to enumeration of six selected trees species with only > 20 cm DBH in 94 plots covering 42.30 ha area. Out of 7 forms, 15 groups and 47 types of TreMs (Larrieu et al., 2018), 4 forms, 5 groups and 14 types were found in the present study (Table 2). Vuidot et al. (2011) found the presence of more microhabitat types as ivy, non-woodpecker cavities, conks, woodpecker cavities, canker, dead crown, cracks, bark pockets, bark losses and bryophytes in five French forests.

TreMs types per plot varied from 1 to 7. Some TOF had more than one habitant types. Due to co-occurrence, habitant type per tree varied from 1 to 6. 6 habitants were found in only one tree of *Cinnamomum camphora* with 8.6 m height and 75 cm DBH (Table 1). Larrieu et al. (2021) found TreMs co-occurrence for 11 TreMs groups. He found six

Table 1: Number and density of TreMs, numbers of trees with habitant numbers in the study area

Number of TOF with TreMs	Density of TOF with TreMs (ha^{-1})	6 habitants	5 habitants	4 habitants	3 habitants	2 habitants	1 habitants
1038	39.51	1	4	8	67	293	665

Note : TOF = Trees Outside Forests

co-occurrences between broad leaves and conifers. These variations with our study might be due to enumeration of more number of living trees (70,958) including 54,740 broadleaves, 16,218 conifers from 2,052 plots. Vuidot et al. (2011) reported the Oaks with a significantly larger number of microhabitats per tree (2.66) in five French forests.

Tree height and DBH are the main elements for TreMs distribution. Height and DBH of the habitat trees in our study area varied from 1.5 to 26 m with an average of 7.12 ± 3.63 m and 5 to 181 cm with an average of 29.86 ± 23.53 cm respectively (Table 4). In his survey of trees with > 7.5 cm DBH, Khanalizadeh et al. (2020) reported the range of 7.5–170 cm with an average of 33.6 cm. Similarly, in the study of trees only > 20 cm DBH, Piechnik et al. (2022) also found a mean DBH of 37 cm. In addition, microhabitat occurrence and DBH have been reported significantly and positively correlated in fir beech trees (Larrieu et al., 2012). Larrieu and Cabanettes (2012) found the first microhabitat occurrence at 41 and 60 cm DBH (median values) for beech and fir respectively. But in contrast, all microhabitats including heavy resinosis and resin drops were more abundance in young stands in Douglas-fir forests of different stand ages and management histories in the Pacific Northwest, U.S.A (Michel & Winter, 2009).

Number of individuals and species of TOF as TreMs with habitat types that were found in the study area are described below.

17 individuals of 13 TOF species had 17 cavities without animal signs (Table 3, Figure 2A) in 14 plots. Cavity as the microhabitat is the most studied TreMs worldwide. Height and DBH of the cavity trees varied from 2.50 to 15 m with an average of 8.55 ± 6.40 m and 18.90 to 95.30 cm with an average of 44.41 ± 23.03 cm respectively (Table 4). Michel & Winter (2009) reported cavities as the low abundant microhabitat on Douglas-fir trees. It was due to the high decay-resistant of resinous wood. Vuidot et al. (2011) reported the increase of non-woodpecker cavities significantly with tree diameter. Bhusal et al. (2015) reported the presence of cavity in 50 trees of eight tree species in the subtropical lowlands of the inner Terai region, south-central Nepal. This higher tree number but lesser species number was due to the study of all cavity types in the Sal forest. They found the similar average values of DBH (38.7 and 47.7 cm) of cavity occurring trees. Woodpecker cavity trees had higher average DBH value (63.13 cm) in the southern part of the Black Forest (south-western Germany) (Basile et al., 2020). Hussain et al. (2013) also reported higher number of cavity-bearing trees (34) in a coniferous forest of Dhirkot, Azad Jammu and Kashmir part of Pakistan which was due to study of all cavity types in the forest.

Eight fungi species (7 of Basidiomycetes and 1 of Corticiaceae) were enumerated in 12 individuals of 6 TOF species (Table 5) in 7 plots. Perennial and annual polypores were also found (Figures 2B and 2C). Mosses were found on 332 individuals

Table 2: Forms, groups and types of TreMs found in the study area

S.N.	Form	Group	Type
1	Cavities	Rot holes	Trunk base rot hole
2	Fruiting bodies of saproxylic fungi and slime moulds	Ephemeral fungal fruiting bodies and slime moulds	Perennial polypores
			Annual polypores
			Cortiaceae
3	Epiphytic, epixylic and parasitic structures	Epiphytic or parasitic crypto- and phanerogams	Bryophytes
			Crustose, foliose and fruticose lichens
			Ivy
			Ferns
			Mistletoe
			Orchids
			Other phanerogams
		Nests	Vertebrate nest
			Invertebrate nest
4	Fresh exudates	Fresh exudates	Sap run

of 31 TOF species (Table 6) in 54 plots. 15 lichen species were found on 377 individuals of 42 TOF species (Figure 2D, Table 7) in 46 plots. 11 ivy (climber) species were found on 65 individuals of 27 TOF species (Figure 2E, Table 8) in 28 plots. 5 fern species were found on 166 individuals of 35 TOF species (Figure 2F, Table 9) in 49 plots. 2 Mistletoe as epiphytic parasitic species were found on 2 individuals of 2 TOF species (Table 10) in 2 plots. 5 orchid species were found on 36 individuals of 22 TOF species (Figure 3G, Table 11) in 16 plots. 12 other phanerogam species were found on 40 individuals of 15 TOF species (Figure 3H, Table 12) in 32 plots.

Similarly, 199 bird nests were found on 139 individuals of 26 TOF species (Figure 3I, Table 3) in 86 plots. 115 individuals of 25 tree species had one

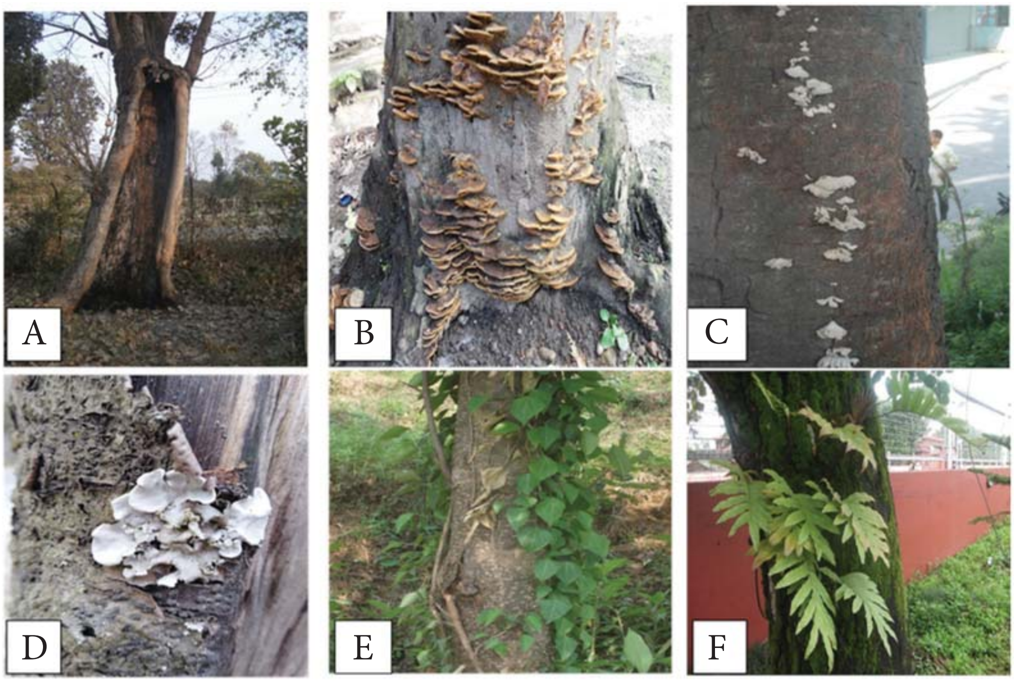

Figure 2: TreMs for, **A.** cavity, **B.** fungi (Perennial polypore), **C.** fungi (Annual polypore), **D.** lichens, **E.** ivy (climber), **F.** ferns

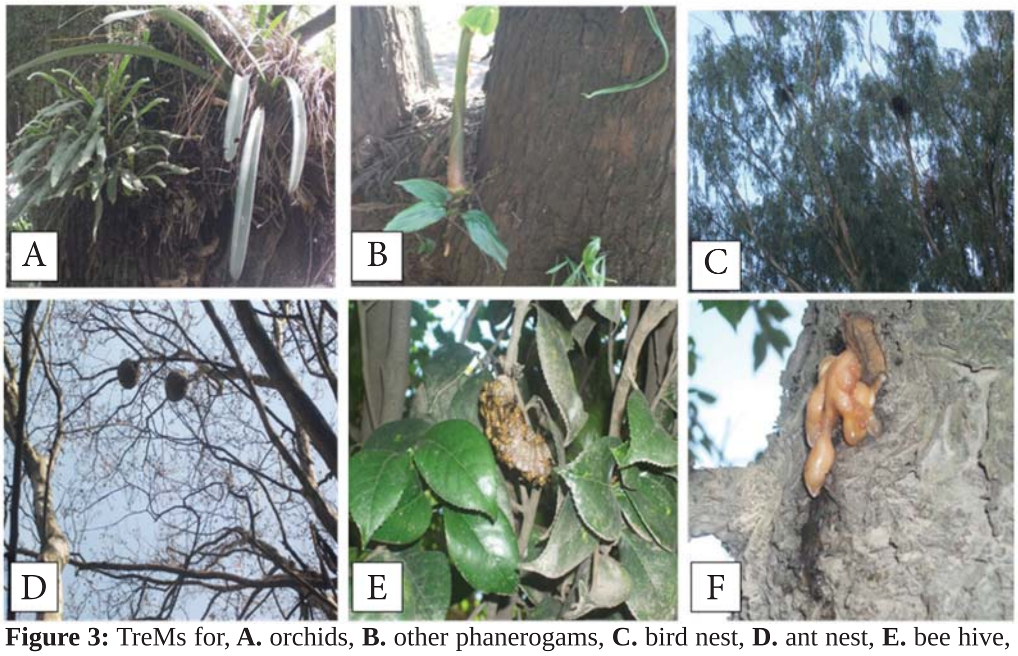

Figure 3: TreMs for, **A.** orchids, **B.** other phanerogams, **C.** bird nest, **D.** ant nest, **E.** bee hive, **F.** sap run

nest in 130 plots, 19 individuals of 11 tree species had two nests in 16 plots, 9 individuals of 6 tree species had three nests in 7 plots and 1 individual of 1 tree species had four nests in 1 plot. 8 individuals of 4 tree species had one ant nest, 1 individual of 1 tree species had more than one ant nest on them (Figure 3J, Table 3) while 3 individuals of 3 tree species had one beehive in each (Figure 3K, Table 3). 27 individuals of 9 TOF species had sap runs (Figure 3L, Table 3) in 13 plots. Michel & Winter (2009) reported drops of resin as the most abundant microhabitat on Douglas-fir trees. It was due to the resinous wood.

Besides the habitats, Seven live animal species were also found in the study area (Table 13).

Table 3: TOF Species showing the presence of cavity, nests, ant nest, beehive and sap run in the study area

S.N.	TOF species	Cavity	1 nest	2 nests	3 nests	4 nests	Ant nest	Bee hives	Sap run
1	*Alnus nepalensis* D. Don		+						
2	*Araucaria bidwillii* Hook.		+						
3	*Araucaria heterophylla* (Salisb.) Franco		+						
4	*Bougainvillea glabra* Choisy	+							
5	*Callistemon citrinus* (Curtis) Skeels	+	+	+					+
6	*Camellia japonica* L.							+	
7	*Casuarina equisetifolia* L.	+							
8	*Cedrus deodara* (Roxb. ex D. Don) G. Don								+
9	*Celtis australis* L.		+	+	+		+		
10	*Choerospondi asaxillaris* (Roxb.) B.L.Burtt		+						
11	*Cinnamomum camphora* (L.) J. Presl		+	+	+	+			+
12	*Dalbergia sissoo* Roxb.		+						
13	*Eucalyptus camaldulensis* Dehn.		+	+	+				
14	*Ficus benghalensis* L.		+						
15	*Ficus benjamina* L.		+						
16	*Ficus elastica* Roxb.		+						
17	*Ficus religeosa* L.		+	+	+				
18	*Grevillea robusta* A. Cunn. ex R. Br.		+	+			+	+	+
19	*Jacaranda mimosifolia* D. Don	+	+		+				+
20	*Juglans nigra* L.		+						
21	*Juglans regia* L.	+							
22	*Lagerstroemia indica* L.		+				+		
23	*Litsea monopetala* (Roxb.) Pers.			+					
24	*Melia azedarch* L.		+	+					
25	*Magnolia champaka* L.								+
26	*Myrica esculenta* Buch-Ham. ex D. Don	+							
27	*Persea americana* Mill.		+						
28	*Pinus roxburghii* Sarg.		+						+
29	*Populus jacquemontiana* Dode.	+	+	+	+				+
30	*Prunus domestica* L.	+							
31	*Pyrus pashia* Buch-Ham. ex D. Don.	+	+						

S.N.	TOF species	Cavity	1 nest	2 nests	3 nests	4 nests	Ant nest	Bee hives	Sap run
32	*Pyrus pyrifolia* (Burn.) Nak.	+							
33	*Rhododendron arboretum* Smith	+							
34	*Salix tetrasperma* Roxb.	+	+						
35	*Syzygium cumini* (L.) Skeels		+	+					
36	*Thuja orientalis* L.	+	+	+			+		+
37	*Ziziphus incurva* Roxb.							+	

Table 4: Minimum, maximum and average height and DBH of trees with TreMs and cavity trees in the study area

TOF with TreMs (n=1038)			Cavity tree (n=17)		
	Height	**DBH**		**Height**	**DBH**
Minimum	1.5	5	Minimum	2.5	18.9
Maximum	26	181	Maximum	15	95.3
Average ± sd*	7.12 ± 3.63	29.86 ± 23.53	Average ± sd	8.55 ± 6.40	44.41 ± 23.03

Note: sd* = standard deviation

Table 5: Fungi occurring TOF species and total fungi recorded in the study area

TOF species	Fungi species
1. *Buddleja asiatica* Lour.	1. *Coriolus* sp.
2. *Grevillea robusta* A. Cunn. ex R. Br.	2. *Fomes fomentarius* L. (Fr.)
3. *Litsea monopetala* (Roxb.) Pers.	3. *Inonotus radiates* (Sowerby) P. Karst
4. *Populus jacquemontiana* Dode.	4. *Schizophyllum commune* Fr.
5. *Pyrus pashia* Buch-Ham. ex D. Don.	5. *Schizophyllum commune* Fr.
6. *Thuja orientalis* L.	6. *Stereopsis* sp.

Table 6: Moss occurring TOF species in the study area

TOF species	TOF species
1. *Alnus nepalensis* D. Don	17. *Lagerstroemia indica* L.
2. *Albizia julibrissin* Durazz.	18. *Litsea monopetala* (Roxb.) Pers.
3. *Borassus flabellifer* L.	19. *Mangifera indica* L.
4. *Buddleja asiatica* Lour.	20. *Manglietia insignis* (Wall.) Blume
5. *Callistemon citrinus* (curtis) Skeels	21. *Melia azedarch* L.
6. *Casuarina equisetifolia* L.	22. *Nyctanthes arbor-tristis* L.
7. *Celtis australis* L.	23. *Phoenix humilis* Royle.
8. *Choerospondias axillaris*(Roxb.) B. L. Burtt	24. *Pinus roxburghii* Sarg.
9. *Cinnamomum camphora* (L.) J. Presl	25. *Populus jacquemontiana* Dode.
10. *Eucalyptus camaldulensis* Dehn.	26. *Pyrus pyrifolia* (Burn.) Nak.
11. *Ficus benjamina* L.	27. *Salix tetrasperma* Roxb.
12. *Ficus religeosa* L.	28. *Schima wallichii* (DC.) Korth.
13. *Grevillea robusta* A. Cunn. ex R. Br.	29. *Syzigium cumini* (L) Skeels
14. *Jacaranda mimosifolia* D. Don	30. *Syzigium jambos* (L.) Alston
15. *Juglans nigra* L.	31. *Thuja orientalis* L.
16. *Juniperus recurva* Buch-Ham. ex D. Don	

Table 7: Lichens occurring TOF species and total lichen species recorded in the study area

TOF species	Lichen species
1. *Alnus nepalensis* D. Don	1. *Canoparmelia* sp.
2. *Araucaria heterophylla* (Salisb.) Franco	2. *Chrysothrix candelaris* (L.) J. R. Laudon
3. *Borassus flabellifer* L.	3. *Dirinaria aegiliata* (Afzel. ex Ach.) B. J. Moore
4. *Buddleja asiatica* Lour.	4. *Graphis stenotera* Vain.
5. *Caryota urens* L.	5. *Candelaria concolor* (Ach.) Flot.
6. *Celtis australis* L.	6. *Herpothallon* sp.
7. *Choerospondias axillaris* (Roxb.) B.L.Burtt	7. *Hyperphyscia adglutinata* (C. Knight) Mull. Arg.
8. *Cinnamomum camphora* (L.) J. Presl	8. *Lepraria* sp.
9. *Citrus aurantifolia* (Christm) Swingle	9. *Parmotrema praesorediosum* (Nyl) Hale.
10. *Citrus maxima* (Burm.) Herr.	10. *Pertusaria* sp.
11. *Eucalyptus camaldulensis* Dehn.	11. *Physcia crispa* (Nyl)
12. *Ficus religiosa* L.	12. *Physcia dubia* (Hoffm.) Lettau
13. *Fraxinus floribunda* Wall.	13. *Physcia sorediosa* (Vain.) Lynge
14. *Grevillea robusta* A. Cunn. ex R. Br.	14. *Pyrenula* sp.
15. *Ilex excelsa* (Wall.) Hook. Fil.	15. *Pyxine* sp.
16. *Jacaranda mimosifolia* D. Don	
17. *Juglans regia* L.	
18. *Juniperus recurve* Buch-Ham. ex D. Don	
19. *Lagerstroemia indica* L.	
20. *Litchi chinensis* Sonner	
21. *Litsea monopetala* (Roxb.) Pers.	
22. *Magnolia soulangeana* Soul.	
23. *Mangifera indica* L.	
24. *Manglietia insignis* (Wall.) Blume	
25. *Magnolia fuscata* Bl.	
26. *Morus alba* L.	
27. *Myrica esculenta* Buch-Ham. ex D. Don	
28. *Nerium indicum* Miller	
29. *Nyctanthes arbor-tristis* L.	
30. *Persea americana* Mill.	
31. *Persea duthiei* (King ex Hook. F.) Kosterm.	
32. *Phoenix humilis* Royle.	
33. *Pinus roxburghii* Sarg.	
34. *Prunus cerasoides* D. Don	
35. *Prunus domestica* L.	
36. *Prunus persica* (L.) Batsch	
37. *Pyrus pyrifolia* (Burn.) Nak.	
38. *Quercus glauca* Thumb.	
39. *Schefflera impress* (C. B. Clarke) Harms	
40. *Schima wallichii* (DC.) Korth.	
41. *Syzygium jambos* (L.) Alston	
42. *Thuja orientalis* L.	

Table 8: Ivy occurring TOF species and total ivy (climbers) species recorded in the study area

TOF species	Climber species
1. *Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1. *Cucurbita maxima* Duchesne
2. *Albizia julibrissin* Durazz.	2. *Dioscore aalata* L.
3. *Alnus nepalensis* D. Don	3. *Diplocyclos palmatus* (L.) C. Jeffrey
4. *Araucaria heterophylla* (Salisb.) Franco	4. *Hedera nepalensis* K. Koch
5. *Bauhinia variegata* L.	5. *Lagenaria siceraria* (Molina) Standl.
6. *Callistemon citrinus* (curtis) Skeels	6. *Macfadyena unguis-cati* (L.) Miers
7. *Celtis australis* L.	7. *Monstera deliciosa* Liebm.
8. *Choerospondias axillaris* (Roxb.) B.L.Burtt	8. *Oplismenus burmannii* (Retz.) P. Beauv.
9. *Cinnamomum camphora* (L.) J. Presl	9. *Sechium edule* (Jacq.) Sw.
10. *Citrus maxima* (Burm.) Herr.	10. *Syngonium podophyllum* Schott
11. *Eucalyptus camaldulensis* Dehn.	11. *Bougainvillea glabra* Choisy
12. *Ficus lacor* Buch-Ham.	
13. *Ficus semicordata* Buch- Ham. ex Sm.	
14. *Grevillea robusta* A. Cunn. ex R. Br.	
15. *Jacaranda mimosifolia* D. Don	
16. *Melia azedarach* L.	
17. *Magnolia champaka* L.	
18. *Phoenix humilis* Royle.	
19. *Pinus roxburghii* Sarg.	
20. *Platanu sorientalis* L.	
21. *Prunus cerasoides* D. Don	
22. *Prunus domestica* L.	
23. *Prunus persica* (L.) Batsch	
24. *Psidium guajava* L.	
25. *Pyrus pashia* Buch-Ham. ex D. Don.	
26. *Pyru spyrifolia* (Burn.) Nak.	
27. *Thuja orientalis* L.	

Table 9: Fern occurring TOF species and total fern species recorded in the study area

TOF species	Fern species
1. *Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1. *Drynaria* sp.
2. *Albizia julibrissin* Durazz.	2. *Dryopteris* sp.
3. *Araucaria heterophylla* (Salisb.) Franco	3. *Microsorum* sp.
4. *Areca catechu* L.	4. *Nephrolepis* sp.
5. *Buddleja asiatica* Lour.	5. *Onychium japonicum* (Thumb.) Kunze. Nom.
6. *Callistemon citrinus* (curtis) Skeels	
7. *Cassia fistula* L.	
8. *Casuarina equisetifolia* L.	
9. *Celtis australis* L.	
10. *Choerospondias axillaris* (Roxb.) B. L. Burtt	
11. *Cinnamomum camphora* (L.) J. Presl	
12. *Dalbergia sissoo* Roxb.	
13. *Eucalyptus camaldulensis* Dehn.	
14. *Ficus benghalensis* L.	
15. *Grevillea robusta* A. Cunn. ex R. Br.	
16. *Jacaranda mimosifolia* D. Don	

TOF species	Fern species
17. *Juglans nigra* L.	
18. *Juglans regia* L.	
19. *Juniperus recurva* Buch-Ham. ex D. Don	
20. *Lagerstroemia indica* L.	
21. *Mangifera indica* L.	
22. *Manglietia insignis* (Wall.) Blume	
23. *Melia azedarach* L.	
24. *Phoenix humilis* Royle.	
25. *Phyllanthus emblica* L.	
26. *Pinus roxburghii* Sarg.	
27. *Populus jacquemontiana* Dode.	
28. *Prunus cerasoides* D. Don	
29. *Psidium guajava* L.	
30. *Pyrus pashia* Buch-Ham. ex D. Don.	
31. *Pyrus pyrifolia* (Burn.) Nak.	
32. *Rhododendron arboreum* Smith	
33. *Salix tetrasperma* Roxb.	
34. *Schima wallichii* (DC.) Korth.	
35. *Thuja orientalis* L.	

Table 10: Mistletoe occurring TOF species and total mistletoe species recorded in the study area

TOF species	Mistletoe species
1. *Callistemon citrinus* (curtis) Skeels	1. *Cuscuta* sp.
2. *Populus jacquemontiana* Dode.	2. *Viscum album* L.

Table 11: Orchids occurring TOF species and total orchid species recorded in the study area

TOF species	Orchid species
1. *Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	1. *Bulbophyllum* sp.
2. *Albizia julibrissin* Durazz.	2. *Cleisostoma* sp.
3. *Albizia procera*(Roxb.) Benth.	3. *Dendrobium* sp.
4. *Bougainvillea glabra* Choisy	4. *Pholitoda* sp.
5. *Callistemon citrinus* (curtis) Skeels	5. *Vanda* sp.
6. *Celtis australis* L.	
7. *Choerospondias axillaris* (Roxb.) B. L. Burtt	
8. *Cinnamomum camphora* (L.) J. Presl	
9. *Dalbergia sissoo* Roxb.	
10. *Eucalyptus camaldulensis* Dehn.	
11. *Ficus religeosa* L.	
12. *Grevillearo busta* A. Cunn. ex R. Br.	
13. *Jacaranda mimosifolia* D. Don	
14. *Juglans nigra* L.	
15. *Juglans regia* L.	
16. *Juniperus recurva* Buch-Ham. ex D. Don	
17. *Litchi chinensis* Sonner	
18. *Melia azedarach* L.	
19. *Platanus orientalis* L.	
20. *Podocarpus neriifolius* D. Don	
21. *Prunus cerasoides* D. Don	
22. *Thuja orientalis* L.	

Table 12: TOF species with other phanerogams and total recorded other phanerogams in the study area

TOF species	Other phanerogams
1. *Areca catechu* (L.F.) Willd.	1. *Alnus nepalensis* D. Don
2. *Callistemon citrinus* (curtis) Skeels	2. *Dischidia* sp.
3. *Casuarina equisetifolia* L.	3. *Ficuslacor* Buch-Ham.
4. *Celtis australis* L.	4. *Ficus religiosa* L.
5. *Cinnamomum camphora* (L.) J. Presl	5. *Fragaria* sp.
6. *Eucalyptus camaldulensis* Dehn.	6. *Hedychium coronarium* J. Koenig
7. *Ficus religiosa* L.	7. *Lycopersicum esculentum* L.
8. *Grevillea robusta* A. Cunn. ex R. Br.	8. *Malvaviscus arboreus* Cav.
9. *Jacaranda mimosifolia* D. Don	9. *Mangifera indica* L.
10. *Mangifera indica* L.	10. *Peperomia pellucida* (L.) A. Dietr
11. *Melia azedarach* L.	11. small herbs (unidentified)
12. *Phoenix humilis* Royle.	12. *Solanum aculeatissimum* Jacq.
13. *Prunus cerasoides* D. Don	
14. *Thespesia lampas* (Cav.) Dalz. & Gibs.	
15. *Thuja orientalis* L.	

Table 13: Total animal species recorded on TOF in the study area

Animal species	English common name
1. *Cornu aspersum* Muller	1. Garden snail
2. Catterpiller	2. Catterpiller
3. *Lasiusniger* L.	3. Black garden ant
4. *Tamias sp.* Illiger	4. Squirrel
5. Tarantula	5. Spider
6. *Apis* sp.	6. Bee
7. *Corvus splendens* Viellot	7. Crow

In the strata

Distribution of TreMs types were not found uniform along the urban rural gradient in the study area. Plotwise average numbers of cavities, fungi, mistletoe, other phanerogams and invertebrate nests were found higher in the urban stratum (Table 14). Average numbers of lichens, vertebrate nests and sap runs were found higher in the suburban stratum. In urban areas, there are reports of decreasing lichen abundance due to higher level of air pollution (Bergamaschi et al., 2007). In case of vertebrate avain richness, there is reduction with increased urbanization (Chace & Walsh, 2006).

Khanalizadeh et al. (2020) found the cavity as the most abundant microhabitat type in both managed (16.5 per ha.) as well as in recently unmanaged (14.2 per ha.) forests. Distribution of cavities depends upon the tree species and tree DBH of different altitudes. Hussain (2013) found more tree population (647) but less cavity bearing trees (5.3%) in upper elevation (2042 m) than less tree population (493) but more cavity bearing trees (10.0% of trees) in lower elevation (1066 m). Similarly, average numbers of moss, ivy, ferns and orchids were found higher in the rural stratum. Vuidot et al. (2011) reported significantly lower occurrence of bryophytes in Fontainebleau than at all the other sites. He stated that presence of bryophytes increased with diameter at a higher rate for "other species" than for oaks or for fir and spruce. Kruskal-Wallis tests of lichens have shown the significant difference between urban-rural strata ($p > 0.05$) (Table 14). Vuidot et al. (2011) found the presence of only ivy was highest in Auberive (14.3%) which significantly differed from Fontainebleau (2.9%). Kruskal-Wallis tests of ferns have shown the significant differences between urban-suburban strata ($p > 0.05$) (Table 14). Similarly, the same test of other phanerogams have shown the significant differences between all the strata ($p \leq 0.05$) (Table 14).

Number of vertebrate nests varied from 1 to 4. Kruskal-Wallis tests of vertebrate nests have shown the significant difference between urban-

Table 14: Plotwise average numbers of TreMs types with SD (±) found in different strata of the study area. Different letters across rows indicate significant difference at p ≤ 0.05 (Kruskal-Wallis tests), (n=209)

S.N.	TreMs (Forms)	TreMs (Types)	Urban	Suburban	Rural
1	Cavities	Trunk base rot hole	0.09±0.3 **a**	0.07±0.25 **a**	0.08±0.4 **a**
2	Fruiting bodies of saproxylic fungi and slime moulds	Annual and perennial polypores of Basidiomycetes, Corticiaceae	0.14±0.5 **a**	0.01±0.12 **a**	0
3	Epiphytic, epixylic and parasitic structures	Bryophytes (moss)	1.47±3.6 **a**	1.12±2.71 **a**	2.52±5.7 **a**
		Crustose, Foliose and fruticose lichens	0.42±1.3 **a**	3.14±15.0 **ab**	2.31±4.9 **b**
		Ivy	0.33±0.9 **a**	0.23±0.79 **a**	0.40±1.6 **a**
		Ferns	0.94±2.2 **a**	0.32±1.01 **b**	1.25±3.4 **ab**
		Mistletoe	0.02±0.15	0	0
		Orchids	0.06±0.2 **a**	0.16±0.76 **a**	0.40±1.6 **a**
		Other phanerogams	0.36±0.7 **a**	0.08±0.28 **b**	0.04±0.2 **c**
		Vertebrate nest	0.55±0.7 **a**	0.63±0.66 **a**	0.19±0.4 **b**
		Invertebrate nest	0.10±0.7 **a**	0.04±0.20 **a**	0
4	Fresh exudates	Sap run	0.14±0.4 **a**	0.21±0.99 **a**	0

rural as well as suburban-rural strata ($p \leq 0.05$) (Table 14). Michel & Winter (2009), in his study found a significant difference of the total number of microhabitats/ha only in between the clear cut stands and the managed young, natural mature, and natural old-growth stands, respectively. On the basis of individual microhabitat types and total number of microhabitats, Khanalizadeh et al. (2020) did not find any significant difference between managed and recently unmanaged forests.

From the present results, the work cannot provide the complete discussion on microhabitat key factors. But, the number and occurrence of microhabitat types were mainly influenced by tree characteristics. From the present findings it can be concluded that lichens were the dominating habitant on TOF, followed by mosses and birds.

Conclusion

This study provides fundamental information about the importance of both TOF and TreMs in terms of biodiversity and its conservation in Kathmandu valley, Nepal. Lichens are the dominating habitant on TOF, followed by mosses and birds microhabitat types are species specific. *Cinnamomum camphora* as individual tree of rural stratum served maximum habitat types (6). Habitat types might or might not be dependent on DBH of the tree. Generally, co-occurrence of microhabitat is more common on trees with greater DBH. Microhabitats are also strata specific because maximum habitat types (7) were found in urban and rural strata. Both urban and rural TOF contributes significantly to biodiversity conservation because maximum habitat types (7) were found in both the strata.

Author Contributions

All authors were involved in concept development, research designing, defining of intellectual content and literature research. B. K. Sharma and B. Shrestha collected the data. B. Shrestha analyzed data and prepared manuscript. R. K. P. Yadav and B. K. Sharma analyzed data and reviewed the manuscript. B. Shrestha, as a corresponding author, is the guarantor for this article.

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Valuation of timber and firewood of trees outside forest along the urban–rural gradient in Kathmandu valley, Nepal

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This study aims to analyze diameter class, quality class, wood production potential and timber and firewood values of trees outside forest along the urban-rural gradient in Kathmandu valley of central Nepal. Inventory was performed in 209 randomly selected points. Circular plots of 20 m radius were used for inventory. All trees (height > 1.3 m and DBH ≥ 5 cm) in the plots were identified to species level and their height, DBH & quality class were recorded. In total 6,210 trees (236.35 ha^{-1}) of 150 species belonging to 111 genera and 57 families were recorded. The total merchantable timber volumes of timber class A and B, and total timber volumes were highest in the urban stratum (537.08, 84.88 and 621.96 cu ft ha^{-1} respectively) followed by rural (442.94, 66.82 and 509.76 cu ft ha^{-1} respectively) and suburban (250.04, 47.31 and 297.35 cu ft ha^{-1} respectively) strata. But due to higher merchantable price of tree species recorded in rural stratum, total market value of class A timber was higher in rural stratum (NPR 7,89,871/US$ 6,085), class B timber was higher in urban stratum (NPR 1,08,255/US$ 834), total timber was higher in rural stratum (NPR 8,70,410/US$ 6,706), firewood was higher in urban stratum (NPR 4,88,709/US$ 3,765) and total wood was higher in urban stratum (NPR 12,95,531/US$ 9,981). *Cinnamomum camphora* was found as tree species with highest market price of total wood value in the study area. The study provides the baseline data of useful timber species through TOF suggesting a need for appropriate timber producing species selection for plantation.

Keywords: Diameter class, merchantable timber, quality class, strata, wood

Trees are an essential part of our life. Trees can also be found outside of the forest areas. FAO (1998) has defined trees outside forest (TOF) as "the trees on the land that fulfils the requirements of forest and other wood land except that the area is less than 0.5 ha and the canopy is < 10%". For example, scattered trees in permanent meadows and pastures; permanent tree crops such as fruit trees and coconut; trees in park and gardens, around buildings and in lines along streets, roads, railways, rivers, streams and canals; and trees in shelterbelts of less than 20 m width and 0.5 ha area. TOF comprises all trees ranging from a single discrete individual tree to systematically managed trees (Kleinn, 2000). TOF includes both trees as well as shrubs (Foresta *at al*., 2013). Bamboo is a part of TOF that is merchantable for house construction (Bhusal & Bashyal, 2020). In some cases, total wood production from TOF is more than that from the forests (Krishnankutty *et al*., 2008). TOF has become an important source for timber globally but still there are no policies related to management, harvest, transit and marketing of timber from TOF (Ghosh & Sinha, 2018). It plays a significant role in meeting the challenges of resource sustainability, poverty

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2 Conservation Development Foundation (CODEFUND), Nepal,

reduction, food security, lessening the pressure on forest resources, conserve farmland, increase agricultural productivity and food supplies (Foresta *et al*., 2013). Besides, TOF also provide the impetus to the growth of wood-based industries and employment opportunities by increasing the extent of area under forest (FSI, 2003) especially more jobs to rural communities (Asanzi *et al*., 2014). TOF are prominent features in many landscapes, strata (urban, suburban and rural) and substrata (linear, clumped and scattered tree formations) (Baffetta *et al*., 2010; DFRS, 2011) and serve a number of ecological and economic functions that might be similar to those of forests in different ways and extent (Kleinn, 2000).

Wood includes all timber, industrial wood, firewood and charcoal (Krishnankutty *et al*., 2008). It is still the most widely used fuel source in the developing countries (FAO, 1999a). A timber readily harvestable is the merchantable timber (Ouattara *et al*., 2014). According to DFRS (2015), a tree can be classified as: quality class A tree (high quality sound tree) - a live tree which would produce at least one 6 m long saw log; quality class B tree (sound tree) –a live tree which would produce at least one 3 m long saw log; and quality class C tree (cull tree) - a live tree not qualified as class A or class B but would produce fire wood only. Forests resources, particularly the timber, face an uncertain future because of high deforestation rate, rapid population growth, timber rights allocation system, forest fees, poor law enforcement, increasing demand for timber and energy and sawmills being export oriented (Oduro *et al*., 2014).

Generally, single trees in areas with lower density attain a larger diameter at breast height (DBH) and as a consequence, greater volume (Bembenek *et al*., 2014). Stem volume is an important parameter to estimate the monetary value of timber (Crecente-Campo *et al*., 2009). Categorization of TOF on the basis of diameter class and timber quality class is necessary for the valuation of the wood (Pompa-García, *et al*., 2009; Bembenek *et al*., 2014). Merchantable value of the wood depends on the species (Mejia *et al*., 2015). Merchantable value gives an idea about the economic importance of a species.

The organized tree planting first started in the Malla Era was continued up to the Rana Era (Poudel, 2010). New species like *Araucaria araucana*, other imported species from Europe along with pines were planted to beautify Kathmandu Valley urban areas and palaces. Later with the introduction of modern urban-environmental planning in the 1960s and 1970s, the Government renovated roads and trails throughout Kathmandu. Again in the 1980s, urban environmental planners introduced a three-line green belt. Trees were also planted along either side of other roads (Poudel, 2010), roadside gardens and traffic islands (Baral and Kurmi, 2005). Many parks were also built during different historical eras. A botanical garden and zoo were also built. Thus, many native as well as exotic tree species were planted.

Kathmandu valley with the rapid urban population growth rate of 3.9 % is one of the fastest growing urban agglomerations in South Asia (Muzzini & Aparicio, 2013). It is characterized not only by the rapid population growth rate in the urban core but also by the rapid expansion of urban sprawl in the periphery. Plant communities are sensitive to urban expansion and therefore may serve as indicators for human-induced land use change (Vakhlamova *et al*., 2014). The rural system usually is rich in natural vegetation (Xiao *et al*., 2017) with more timber production whereas due to rapid urbanization, TOF formations have increased with less timber production in urban area. Thus tree species selection for afforestation in TOF will help to minimize the demand-supply gap of timber (Shrivastav *et al*., 2012).

TOF are little recognized in forest resources assessments, and it is only recently that TOF started receiving attention from the research community and the general public (Kleinn, 2000). Nepal's annual import of wood and wooden materials exceeds NPR 6 billion (RSS, 2019.). In this context, the study of TOF in terms of timber production would be important (Oli, 2002). Since FY 2004/05, the Department of Forests Research and Survey (now the Forest Research and Training Center), Government of Nepal has started the assessment of TOF at national level (FAO, 2009). But it is limited only to volume assessment by diameter class. The assessments of TOF in terms of timber and firewood production along the urban-rural gradient are lacking. In this background, this study aims to analyze diameter class, quality class, wood production potential and timber and firewood values of TOF along the urban-rural gradient in Kathmandu valley of central Nepal.

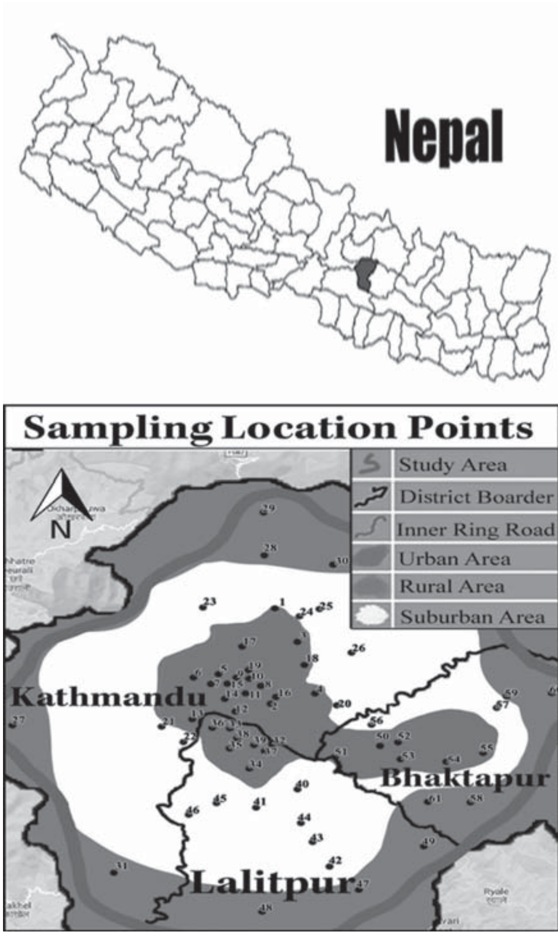
Materials and methods

Study area

The study was carried out in Kathmandu valley (ca. 66,500 ha in area), which includes three districts namely, Kathmandu, Lalitpur and Bhaktapur of Bagmati Province in the middle hill region of central Nepal (ICIMOD, 2007; Figure 1). This bowl-shaped valley extends between 27°32’13” N to 27°49’10” N latitude and 85°11’31” E to 85°31’38” E longitude. It’s elevation ranges between 1,100–2,700 m a.s.l. (Mishra *et al.*, 2019). It is characterized by sub-tropical vegetation and has a distinct monsoon climate with hot and wet summers and cold and dry winters. The average annual minimum and maximum temperature are 1.6°C in January and 31.9°C in April respectively and the average annual rainfall is 1,509 mm (based on DHM data between 2000-2018).

Sampling and data collection

A two-phase sampling method was applied (Lister *et al.*, 2011). In first phase, the study area was divided into 500 m x 500 m grids (n = 2800) (Figure 1). A total of 1,046 sites with TOF were identified under urban, suburban and rural stratum categorized on the basis of population and urban development (GoN, 2014). Google Earth image interpretation showed that more sites with TOF were found in urban (440) stratum than in suburban (366) and rural (240) strata. Twenty percent of sites with TOF from three strata [urban



S.N.	Locations	S.N.	Locations	S.N.	Locations
1	Basundhara	22	Chovar	43	Thaiba
2	Singhdarbar	23	Nepaltar	44	Harisiddi
3	Dhumbarahi	24	Bansbari	45	Bhainsepati
4	Tilganga	25	Mahankal	46	Khokana
5	Dhobichaur	26	Bauddha	47	Godavari
6	Bijeswori	27	Thankot	48	Tahakhel
7	Kankeswori	28	Tokha	49	Lamatar
8	Dillibazar	29	Jhor	50	Gatthaghar
9	Ratna park	30	Budhanilkantha	51	Lokanthali
10	Bag bazar	31	Pharping	52	Naya Thimi
11	Bhrikuti mandap	32	Shankhamul	53	Shankhadhar Chowk
12	Tripureswor	33	Kopundol	54	Sallaghari
13	Balkhu	34	Lagankhel	55	Siddhapokhari
14	Sundhara	35	Jawalakhel	56	Sano thimi
15	Newroad	36	Sanepa	57	Jhaukhel
16	Anam Nagar	37	Mangalbazar	58	Doleswor
17	Samakhushi	38	Pulchowk	59	Changu
18	Chabahil	39	Patandhoka	60	Chaling
19	Durbarmarg	40	Imadol	61	Anantalingeswor
20	Sinamangal	41	Khumaltar		
21	Kirtipur	42	Badegaun		

Figure 1: Map of the study area. The distribution of the sample points in urban, suburban and rural strata

(88), suburban (73) and rural (48) strata] were selected randomly for the field survey (Figure 1). In second phase field survey was done. Circular sample plots with 20 m radii (area = 0.13 ha) were used for the survey (FRA/DFRS, 2011). Plant characteristics (height, DBH and quality class) of woody plants (trees and shrubs) with height > 1.3 m and diameter at breast height (DBH) ≥ 5 cm were recorded. DBH was measured at 1.3 m above the ground using diameter tape and the tree height was measured using Suunto clinometer (PM-5/360 PC). Tree quality class was also noted for individual trees. Plants were identified to species level based on herbarium specimen prepared following standard procedure (Bridson & Forman, 1998). The vernacular names of the plant species were also recorded with the help of local people and verified with Sharma (2014). Identification was done by using literatures such as Flora of Kathmandu Valley (Malla *et al.*, 1986), followed by comparison with identified specimens previously deposited at Tribhuvan University Central Herbarium (TUCH), Nepal, scientific names were determined. Press *et al*. (2000) and Plants of the World Online (https://powo.science.kew.org/) were followed for plant nomenclature.

Species richness of the study area and across the strata were estimated with respect to the area sampled at the study area and each stratum. Average species richness was calculated as the total number of species recorded per plot (Dorji *et al*., 2014). Growth forms of the plants were based on Sharma (2014). Frequency of the individual tree species were also calculated (Danekhu *et al*., 2016-18).

Data analysis

DBH and height of the recorded trees were used.

Estimation of above ground biomass of trees

The total above ground tree biomass was estimated using allometric equation developed by Petersson *et al.* (2012).

$$AGTB = 0.0509\ \rho\ D^2\ H$$

Where, AGTB = aboveground tree biomass (kg), ρ= wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), H = tree height (m).

Sharma & Pukkala (1990) and Zanne *et al*. (2009) were used for wood specific gravities of tree species. For the tree/shrub species for which wood specific gravity data were not available, the arithmetic mean of all known tree/shrub species in the study area was used (Brown *et al*., 1989).

Estimation of biomass of merchantable timber and firewood

Merchantable weights of log of quality class A tree and quality class B tree were calculated only for trees with DBH ≥30 cm as such trees are regarded as mature trees (DoF, 2004 and Brown *et al*., 2020). The biomass of merchantable timber of log of class A tree and class B tree were estimated using following allometric equations adapted from Petersson *et al.* (2012).

Merchantable weight of log of class A tree $AGTB = 0.0509 * \rho * D^2 * 6$ (kg)

Merchantable weight of log of class B tree $AGTB = 0.0509 * \rho * D^2 * 3$ (kg)

Where, AGTB = aboveground tree biomass (kg), ρ= wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm), 6 and 3 are the lengths (m) of merchantable logs of class A and class B trees respectively.

The biomass of firewood was calculated for timber yielding trees by subtracting the biomass of merchantable timber from the total AGTB of trees. The total AGTB of trees of class C were also accounted as fire wood biomass. These biomasses were converted into kg ha^{-1}.

Economic valuation of merchantable timber and firewood

As the merchantable timber are sold in cu ft measurement, biomass of merchantable timber of class A and class B trees in ton ha^{-1} were converted into volume (cubic feet) by multiplying with 40

(Wallis, 1970). Market value of merchantable timber of class A and B were calculated by multiplying the merchantable volumes by the per cu ft market price of timber. Unlike timber, the firewood is sold in per kg measurement. So, the market value of firewood was calculated by multiplying the firewood biomass by per kg market price of firewood. Retail market prices of class A, class B logs and firewood of tree species were collected from the retail depots (n = 4) (Ahmed, 2008). The average market prices were used for valuation. For the tree species for which market prices were not available (both timber and firewood), the average values of market prices of all tree species were used (Bembenek *et al*., 2014). Market values of timber of class A and class B were added to that of firewood to get the total economic value of individual tree species. All these values were then summed up to get the total economic value of all tree species except the bamboo. As bamboos are sold as culms (Bhusal & Bashyal, 2020), their merchantable values were calculated by multiplying the density per hectare by average market price. All these prices were then summed up to get the total merchantable value of wood in each stratum and the study area. Economic values in NPR were converted into US$ by multiplying with 129.8 (1 US$ = 129.8 NPR, accessed on 11/7/2022)

Statistical analysis

First the data were standardized. Standardized values are calculated by subtracting the sample mean of each variable from each observation and dividing this difference by the sample standard deviation (Gotelli & Ellison, 2013). Those values were then tested for normality. However, the data were not normal and their normality did not improve even after transformation so Kruskal-Wallis test with post-hoc Mann-Whitney test at $p \leq 0.05$ were used for comparison among groups. PAST (V 4.09; Hammer *et al*., 2001) was used for analysis.

Results

Plant species diversity

A total of 150 species of plants [trees (n=121) and shrubs (n=29)] belonging to 111 genera and 57 families were enumerated from the study area. Though the average species richness was found to be higher in urban stratum than in suburban and rural strata, Kruskal-Wallis test followed by Mann-Whitney test showed that there are no significant differences among the strata (Table 1 and Table 2).

Table 1: Species richness of trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Number of plots, species richness (range), species richness ha^{-1} and average species richness (ha^{-1}) in three strata are shown. Different superscript letters indicate statistical significance at $p<0.05$ (Kruskal-Wallis test followed by Mann Whitney test)

Strata	Number of plots	Species richness (range)	Species richness (ha^{-1})	Average species richness (ha^{-1})
Urban	88	109 (1-21)	9.85	55.95 ± 31.67^{a}
Suburban	73	89 (1-16)	9.7	46.31 ± 26.99^{a}
Rural	48	85 (2-15)	14.09	45.74 ± 23.35^{a}

Table 2: Scientific name, vernacular name, English name, family and frequency of species of trees outside forest species found in the study area

S.N.	Scientific name	Vernacular name	English name	Growth form	Family	Frequency (%)
1	*Acacia catechu* (L.F.) Willd.	Khayar	Cutch tree	Tree	Leguminosae	0.48
2	*Acacia nilotica* (L.) Willd. ex Del.	Babool	Gum arabic tree	Tree	Leguminosae	0.96
3	*Acer oblongum* Wall. ex DC.	Phirphire	Himalayan maple	Tree	Sapindaceae	0.48
4	*Agave cantula* Roxb.	Ketuke	Century plant	Shrub	Agavaceae	0.48
5	*Alangium chinense* (Lour.) Harms	Baman patti	Chinese alangium	Tree	Alangiaceae	0.48
6	*Albizia julibrissin* Durazz.	Rato siris	Mimosa tree	Tree	Leguminosae	9.09
7	*Albizia procera* (Roxb.) Benth.	Seto siris	White siris tree	Tree	Leguminosae	0.96
8	*Alnus nepalensis* D. Don	Uttis	Alder	Tree	Betulaceae	10.05
9	*Alstonia neriifolia* D. Don			Tree	Apocynaceae	1.91
10	*Alstonia scholaris* (L.) R. Br.	Chatiwan	Devil's tree	Tree	Apocynaceae	3.35
11	*Anthocephalus chinensis* (Lam.) A. Rich. ex Walp.	Kadamgachi	Kadam	Tree	Rubiaceae	0.48
12	*Araucaria bidwillii* Hook.	Dhengre sallo	Monkey puzzle	Tree	Araucariaceae	6.70
13	*Araucaria columnaris* J. R. Forst & Hook.		Coral reef araucaria	Tree	Araucariaceae	0.48
14	*Araucaria heterophylla* (Salisb.) Franco		Living Christmas tree	Tree	Araucariaceae	8.13
15	*Areca catechu* L.	Bhale supari	Betel nut	Tree	Palmae	1.44
16	*Artocarpus integra* (Thumb.) Merr.	Rookh katahar	Jack fruit	Tree	Moraceae	0.48
17	*Azadirachta indica* A. Juss.	Neem	Neem tree	Tree	Meliaceae	2.39
18	*Bambusa nepalensis* Stapleton	Bansa	Bamboo	Grass	Gramineae	3.83
19	*Bauhinia variegata* L.	Koiralo	Purple orchid tree	Tree	Leguminosae	2.87
20	*Berberis asiatica* Roxb. ex DC.	Chutro	Barberry	Shrub	Berberidaceae	0.96
21	*Borassus flabellifer* L.	Taad	Toddy palm	Tree	Palmae	5.74
22	*Bougainvillea glabra* Choisy	Kagaj phool	Paper flower	Shrub	Nyctaginaceae	2.39
23	*Brugmansia arborea* Pers.	Dhaturo	Angel's trumplet	Shrub	Solanaceae	1.91
24	*Buchanania latifolia* Roxb.	Chiraungi	Cuddaph almond	Tree	Anacardiaceae	0.48
25	*Buddleja asiatica* Lour.	Bhimsenpati	Butterfly bush	Shrub	Loganiaceae	8.61
26	*Burretiokentia vieillardii* Pic. Serm.	Taad	Tiger palm	Tree	Palmae	0.48
27	*Callistemon citrinus* (Curtis) Skeels	Kalki phool	Bottle brush	Tree	Myrtaceae	19.14
28	*Camellia japonica* L.	Chinia guransa	Garden camellia	Shrub	Theaceae	0.96

S.N.	Scientific name	Vernacular name	English name	Growth form	Family	Frequency (%)
29	*Carica papaya* L.	Mewa	Papaya	Tree	Caricaceae	2.39
30	*Carya illinoensis* (Wangenheim) K. Koch	Picanut	Pecan	Tree	Juglandaceae	0.48
31	*Caryota urens* L.	Jagar	Fish- tail palm	Tree	Palmae	0.96
32	*Cassia fistula* L.	Raj brichya	Cassia pods	Tree	Leguminosae	0.48
33	*Cassia mimosaides* L.	Amala jhar	Tooth cup	Shrub	Leguminosae	0.48
34	*Casuarina equisetifolia* L.	Jangali jhyau	Whistling pine	Tree	Casuarinaceae	0.48
35	*Cedrus deodara* (Roxb. ex D. Don) G. Don	Devdaru	Deodar	Tree	Pinaceae	0.96
36	*Celtis australis* L.	Khari	Europian nettle tree	Tree	Ulmaceae	29.67
37	*Cestrum nocturnum* L.	Rat ki rani	Night jasmine	Shrub	Solanaceae	0.48
38	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	Lapsi	Nepali hog plum	Tree	Anacardiaceae	11.96
39	*Cinnamomum camphora* (L.) J. Presl	Kapoor	Camphor	Tree	Lauraceae	41.15
40	*Cinnamomum tamala* (Buch-Ham) Nees & Eberm.	Tejpatta	Cinnamon leaf	Tree	Lauraceae	0.48
41	*Citrus aurantifolia* (Christm) Swingle	Kagati	Lemon	Tree	Rutaceae	5.74
42	*Citrus jambhiri* Lush.	Jyamir	Florida lemon	Tree	Rutaceae	0.96
43	*Citrus limon* (L.) Burn. F.	Nibuwa	Lime	Tree	Rutaceae	1.91
44	*Citrus maxima* (Burm.) Herr.	Bhogate	Pummelo	Tree	Rutaceae	18.18
45	*Citrus reticulata* Blanco.	Suntala	Mandarin orange	Tree	Rutaceae	0.48
46	*Cotinus coggygria* (Scop.)	Rato peepal	Smoke bush	Shrub	Anacardiaceae	0.48
47	*Croton roxburghii* Balakrishnan	Ach	Croton	Tree	Euphorbeaceae	0.48
48	*Cycus pectinata* Buch.-Ham.	Kalbal	Cycus	Tree	Cycadaceae	0.96
49	*Cyphomandra betaceae* (Cav.) Sendt	Tyamter	Tree tomato	Shrub	Solanaceae	0.96
50	*Dalbergia sissoo* Roxb.	Sisau	Indian rosewood	Tree	Leguminoceae	4.31
51	*Diospyros kaki* Thunb.	Haluwabed	Persimon	Tree	Ebenaceae	4.31
52	*Diploknema butyracea* (Roxb.) Lam.	Chiuri	Butter fruit	Tree	Sapotaceae	0.48
53	*Duranta erecta* L.	Nil kanda	Golden dewdrops	Shrub	Verbenaceae	0.96
54	*Elaeocarpus sphaericus* (Gaertn.) K. Schum.	Rudrakshya	Utrasum bead tree	Tree	Elaeocarpaceae	5.74
55	*Eriobotrya japonica* (Thumb.) Lindl.	Laukat	Loquat	Tree	Rosaceae	0.48
56	*Erythrina arborescens* Roxb.	Theki kath	Himlayan coral bean	Tree	Leguminosae	0.48
57	*Erythrina stricta* Roxb.	Phaledo	Indian coral tree	Tree	Leguminosae	1.91
58	*Eucalyptus camaldulensis* Dehn.	Masala	River red gum	Tree	Myrtaceae	4.78
59	*Euphorbia pulcherrima* Willd. Ex Klotzsch	Lalupate	Poinsettia	Shrub	Euphorbeaceae	1.91

S.N.	Scientific name	Vernacular name	English name	Growth form	Family	Frequency (%)
60	*Ficus auriculata* Lour.	Timilo	Roxburgh fig	Tree	Moraceae	2.39
61	*Ficus benghalensis* L.	Bar	Banyan fig	Tree	Moraceae	5.74
62	*Ficus benjamina* L.	Sami	Weeping fig	Tree	Moraceae	4.78
63	*Ficus elastica* Roxb.	Rubber plant	Rubber plant	Tree	Moraceae	7.18
64	*Ficus lacor* Buch.-Ham.	Kabhro	Java fig	Tree	Moraceae	5.26
65	*Ficus neriifolia* Sm.	Dudhilo	Willow leaf fig	Tree	Moraceae	0.48
66	*Ficus religiosa* L.	Pipal	Sacred fig	Tree	Moraceae	25.84
67	*Ficus semicordata* Buch-Ham ex Sm.	Khanayo	Drooping fig	Tree	Moraceae	0.48
68	*Fraxinus floribunda* Wall.	Lankure	Ash	Tree	Oleaceae	1.44
69	*Ginkgo biloba* L.		Maidenhair tree	Tree	Ginkgoiaceae	0.48
70	*Gossypium arborium* L.	Kapas	Cotton plant	Shrub	Malvaceae	0.48
71	*Grevillea robusta* A. Cunn. ex R. Br.	Kagiyo	Silky oak	Tree	Proteaceae	29.19
72	*Hibiscus brackenridgei* A. Gray		Rose mallow	Shrub	Malvaceae	0.48
73	*Hibiscus rosa-sinensis* L.	Ghanti phool	China rose	Shrub	Malvaceae	1.44
74	*Homalium napaulense* (DC.) Benth.	Falame kanda		Tree	Flacourtiaceae	0.48
75	*Ilex excelsa* (Wall.) Hook. Fil.	Pwanle		Tree	Aquifoliaceae	1.44
76	*Jacaranda mimosifolia* D.Don	Nilo phool	Jacaranda	Tree	Bignoniaceae	19.14
77	*Jasminum mesnyi* Hance	Double jai	Primrose jasmine	Shrub	Oleaceae	0.48
78	*Juglans nigra* L.	Hade okhar	Black walnut	Tree	Juglandaceae	4.31
79	*Juglans regia* L.	Dante okhar	English walnut	Tree	Juglandaceae	2.87
80	*Juniperus chinensis* L.	Dhupi	Chinese juniper	Shrub	Cupressaceae	0.96
81	*Juniperus communis* L.	Dhupi	Pencil cedar	Shrub	Cupressaceae	0.48
82	*Juniperus indica* Bertol.	Dhupi	Black juniper	Shrub	Cupressaceae	6.22
83	*Juniperus recurva* Buch.-Ham. ex D. Don	Dhupi	Himalayan juniper	Tree	Cupressaceae	3.35
84	*Lagerstroemia indica* L.	Asare phool	Crape myrtle	Tree	Lythraceae	12.44
85	*Lagerstroemia parviflora* Roxb.	Bot dhairo	Crepe flower	Tree	Lythraceae	0.48
86	*Lagerstroemia reginae* Roxb.	Thulo asare	Queen's crape myrtle	Shrub	Lythraceae	0.48
87	*Leucaena leucocephala* (Lam.) De Wit	Epil	Ipil ipil	Tree	Leguminoseae	0.96
88	*Ligustrum confusum* Decne.	Kanike rookh	Privet	Tree	Oleaceae	0.48
89	*Lindera pulcherrima* (Nees) Benth. ex Hook. F.	Shyal phusre	Wild privet	Tree	Lauraceae	0.96
90	*Litchi chinensis* Sonner	Lichi	Lychee	Tree	Santalaceae	0.96
91	*Litsea monopetala* (Roxb.) Pers.	Kutmiro	Many-flowered litsea	Tree	Lauraceae	3.83
92	*Macadamia integrifolia* Maiden & Betche		Queensland nut	Tree	Proteaceae	0.48

S.N.	Scientific name	Vernacular name	English name	Growth form	Family	Frequency (%)
93	*Madhuca longofolia* (Koeing)	Chiuri	Macbride	Tree	Sapotaceae	0.48
94	*Magnolia soulangeana* Soul.	Neel kamal	Saucer magnolia	Tree	Magnoliaceae	0.48
95	*Mahonia nepaulensis* DC.	Jamanemandro	Mahonia	Tree	Berberidaceae	0.48
96	*Malvaviscus arboreus* Cav.	Khursani phool	Turkcap	Shrub	Malvaceae	0.96
97	*Mangifera indica* L.	Aap	Mango	Tree	Anacardiaceae	7.18
98	*Manglietia insignis* (Wall.) Blume	Rookh kamal		Tree	Magnoliaceae	5.74
99	*Melia azedarach* L.	Bakaino	China berry	Tree	Meliaceae	14.35
100	*Michelia champaka* L.	Champ	Champaca	Tree	Magnoliaceae	4.78
101	*Michelia fuscata* Bl.	Kankakchampa	Banana shrub	Shrub	Magnoliaceae	0.48
102	*Miliusa velutina* (Dunal) Hook. f. & Thombs	Kali kath	Velveti miliusa	Tree	Annonaceae	0.48
103	*Morus alba L.*	Kimbu	Common mulberry	Tree	Moraceae	5.74
104	*Murraya koenigii* (L.) Sprengel	Kadi patta	Curry tree	Tree	Rutaceae	0.48
105	*Musa paradisiaca* L.	Kera	Banana	Shrub	Musaceae	0.96
106	*Myrica esculenta* Buch-Ham. ex D. Don	Kafal	Box myrtale	Tree	Myricaceae	0.96
107	*Myrsine capitellata* Wall.	Seti kath		Tree	Myrsinaceae	0.48
108	*Nerium indicum* Miller	Karbir	Indian oleander	Tree	Apocynaceae	1.44
109	*Nerium oleander* variegatum	Kannel	Kaner	Tree	Apocynaceae	2.39
110	*Nyctanthes arbor-tristis* L.	Parijat	Coral jasmine	Tree	Oleaceae	7.66
111	*Persea americana* Mill.	Ghiu phal	Avocado	Tree	Lauraceae	8.61
112	*Persea duthiei* (King ex Hook. F.) Kosterm.	Kaulo	Duthiei bay tree	Tree	Lauraceae	2.87
113	*Phoenix humilis* Royle.	Khajur	Dwarf date palm	Tree	Palmae	0.96
114	*Phoenix sylvestris* Roxb.	Taadi	Wild date palm	Tree	Palmae	0.48
115	*Phyllanths emblica* L.	Amala	Emblic	Tree	Euphorbeaceae	2.87
116	*Pinus roxburghii* Sarg.	Khote salla	Chir pine	Tree	Pinaceae	14.35
117	*Platanus orientalis* L.	Chinar	Oriental plane	Tree	Platanaceae	0.48
118	*Podocarpus neriifolius* D. Don	Gunsi	Oleander Podocarp	Tree	Podocarpaceae	0.48
119	*Populus jacquemontiana* Dode.	Lahare pipal	Poplar	Tree	Salicaceae	11.96
120	*Prunus avium* L.	Cherry	Sweet cherry	Tree	Rosaceae	0.48
121	*Prunus cerasoides* D. Don	Paiyun	Himalayan cherry	Tree	Rosaceae	9.57
122	*Prunus domestica* L.	Aaloo bokhada	Europian plum	Shrub	Rosaceae	7.18
123	*Prunus persica* (L.) Batsch	Aaroo	Peach	Tree	Rosaceae	8.61
124	*Psidium guajava* L.	Amba	Guava	Tree	Myrtaceae	17.22
125	*Punica granatum* L.	Anar	Pomegranate	Tree	Punicaceae	4.78
126	*Pyrus communis* L.	Naspati	Europian pear	Tree	Rosaceae	0.48

S.N.	Scientific name	Vernacular name	English name	Growth form	Family	Frequency (%)
127	*Pyrus crenata* Buch.-Ham. ex D. Don.	Naspati	Wild pear	Tree	Rosaceae	0.96
128	*Pyrus malus* L.	Syau	Apple	Tree	Rosaceae	0.96
129	*Pyrus pashia* Buch.-Ham. ex D. Don.	Mayal	Wild Himalayan pear	Tree	Rosaceae	5.74
130	*Pyrus pyrifolia* (Burn.) Nak.	Naspati	Asian pear	Tree	Rosaceae	9.57
131	*Quercus glauca* Thumb.	Falant	Ring-cupped oak	Tree	Fagaceae	0.48
132	*Rhododendron arboreum* Smith	Lali guransa	Tree rhododendron	Tree	Ericaceae	0.96
133	*Ricinus communis* L.	Andir	Castor bean	Shrub	Euphorbiaceae	0.48
134	*Salix tetrasperma* Roxb.	Bainsa	Indian willow	Tree	Salicaceae	11.00
135	*Sambucus hookeri* Rehder	Galeni	Elder	Tree	Sambucaceae	6.70
136	*Sapindus mukorossi* Gaertn.	Rittha	Soap berry	Tree	Sapindaceae	0.96
137	*Schefflera impressa* (C. B. Clarke) Harms	Simaal	Schefflera vine	Tree	Araliaceae	1.44
138	*Schima wallichii* (DC.) Korth.	Chilaune	Needlewood tree	Tree	Theaceae	6.22
139	*Spathodea campanulata* P. Beauv		African tulip tree	Tree	Bignoniaceae	0.48
140	*Syzygium cumini* (L) Skeels	Jamuna	Malabar plum	Tree	Myrtaceae	8.61
141	*Syzygium jambos* (L.) Alston	Gulab jamun	Rose apple	Tree	Myrtaceae	2.87
142	*Tecoma stans* (L.) H. B. K.	Ghata pushpi	Yellow bell	Shrub	Bignoniaceae	0.96
143	*Thespesia lampas* (Cav.) Dalz. & Gibs.	Ban kapas	Common mallow	Shrub	Malvaceae	1.91
144	*Thuja orientalis* L.	Mayur Pankhi	Cedar	Tree	Cupressaceae	29.19
145	*Toona ciliata* M. Roem.	Tooni	Indian cedar	Tree	Meliaceae	0.48
146	*Trachycarpus* sp. H. Wendl.	Taad	Fan palm	Tree	Palmae	0.96
147	*Vitex negundo* L.	Simali	Five-leaved chaste tree	Shrub	Verbenaceae	0.96
148	*Woodfordia fruticosa* (L.) Kurz	Dhangero	Fire flame bush	Shrub	Lythraceae	0.48
149	*Zanthoxylum armatum* DC.	Timur	Prickly ash	Tree	Rutaceae	0.48
150	*Ziziphus incurva* Roxb.	Hade bayar	Bead plum	Tree	Rhamnaceae	1.44

Tree density, tree height and stem DBH

The average tree density in the study area was 236.35±173.12 ha^{-1}. Maximum height of the tree was 31.50 m with an average of 6.83±3.77 m. Similarly, maximum DBH of the stem was 203 cm with an average of 21.44±19.49 cm. The average tree density was higher in suburban stratum (248.44±198.56 ha^{-1}) than in urban (232.58±155.08 ha^{-1}) and rural (224.88±165.31 ha^{-1}) strata (Table 3). However, the difference was not significant. The tallest tree (31.50 m) and widest tree (203 cm) were found in urban stratum. The urban stratum was found to have significantly taller and wider trees than suburban and rural strata (Table 3).

Table 3: Average tree density (±SD), maximum and average (±SD), tree height and maximum and average (±SD) stem DBH of trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Different superscript letters indicate statistical significance at p<0.05.

Strata	Average Tree Density (Number of stem ha^{-1})	Tree Height (m)		Stem DBH (cm)	
		Maximum	Average	Maximum	Average
Urban	232.58±155.08 [a]	31.5	7.64±4.63[a]	203	22.80±19.85[a]
Suburban	248.44±198.56 [a]	20.3	6.43±2.97[bc]	157.3	20.36±16.80[b]
Rural	224.88±165.31 [a]	23	5.92±2.68[c]	187	20.62±22.59[b]

Tree density by quality class and stem diameter class

The average density of merchantable trees of quality class A, quality class B and quality class C in the study are were 20.90±37.01 ha^{-1}, 13.09±22.16 ha^{-1} and 202.37±178.53 ha^{-1} respectively. The average density of merchantable trees of quality class A was found to be significantly higher ($p<0.05$) in urban stratum than in rural stratum but that did not differ significantly from that in suburban stratum (Table 4). Moreover, the differences in average densities of merchantable trees of quality class B and C were not significant among three strata ($p<0.05$).

Similarly, the average stem densities of diameter classes 5-9.90 cm, 10-19.90 cm, 20-29.90 cm and ≥ 30 cm in the study area were found to be 79.51±107.30 ha^{-1}, 64.28±77.09 ha^{-1}, 34.94±36.62 ha^{-1} and 57.24±60.92 ha^{-1} respectively (Table 4). There were no significant differences in the average stem densities across different strata except for the diameter class 20-29.90 cm. Urban and suburban strata were found to have significant stem density of diameter class 20-29.90 cm than the rural stratum (Table 4).

Table 4: Average densities (±SD) of trees by tree quality classes and stem diameter classes of trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Different superscript letters indicate statistical significance at p<0.05.

Strata	Average density of trees by quality class (ha^{-1})			Average stem density by diameter class (ha^{-1}) (cm)			
	A	B	C	5-9.90	10-19.90	20-29.90	≥30
Urban	28.20±45.50[a]	15.37±23.57[a]	189.02±160.72[a]	66.26±93.69[a]	68.97±71.06[a]	37.06±35.84[a]	60.29±60.12[a]
Suburban	18.85±29.60[ab]	11.77±21.87[a]	217.83±207.20[a]	87.83±119.45[a]	61.35±83.17[a]	40.10±43.78[a]	59.17±67.38[a]
Rural	10.61±25.96[b]	10.94±19.87[a]	203.35±163.62[a]	92.80±111.09[a]	60.16±79.29[a]	23.20±20.75[b]	48.72±51.80[a]

Volume and biomass of merchantable timber and firewood

Out of 53 tree species with merchantable timber recorded in the study area, 13 species could yield timber of quality class A, 13 could yield timber of quality class B, while 27 could yield timber of both quality class A and B (Appendix I).

The total volume of merchantable timber in the study area was 625.51 cu ft ha^{-1} with 549.33 cu ft ha^{-1} and 76.18 cu ft ha^{-1} as volumes of merchantable timber class A and class B. Total biomass of firewood was 50840.85 kg ha^{-1}. The volume of merchantable timber was highest in the urban stratum followed by rural and suburban strata while biomass of firewood was highest in urban stratum followed by suburban and rural strata (Table 5).

Table 5: Volume of merchantable timber and biomass of firewood from trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Volume ha^{-1} by quality class and total volume ha^{-1} of merchantable timber and total biomass ha^{-1} of firewood

Strata	Class A timber (cu ft ha^{-1})	Class B timber (cu ft ha^{-1})	Total timber (cu ft ha^{-1})	Firewood (kg ha^{-1})
Urban	537.08	84.88	621.96	55835.49
Suburban	250.04	47.31	297.35	39410.01
Rural	442.94	66.82	509.76	39032.12

Market value of merchantable wood

The total market values were calculated based on the per unit market price of the timber and firewood in the study area (Appendix II). Based upon the market values of individual tree species. (Appendix III), the total market values of timber class A, timber class B, total timber, firewood and total wood from the TOF were found to be NPR. 746,613 (US$ 5,752), NPR. 96,358 (US$ 742), NPR. 842,971 (US$ 6,494), NPR. 516,612 (US$ 3,980) and NPR. 1362,880 (US$ 10,500) ha^{-1}. The market value of total merchantable timber was highest in the rural stratum followed by urban and suburban strata while that of firewood was highest in urban stratum followed by suburban and rural strata (Appendix IV, Appendix V, Appendix VI and Table 6).

Cinnamomum camphora was the tree species with highest market value of timber class A, timber class B, total timber and total wood value ha^{-1} as (NPR. 229,851) (US$ 1,771), (NPR. 17,399) (US$ 134), (NPR. 247,250) (US$ 1,905) and (NPR. 2,96,101) (US$ 2,281) in the study area (Table 7). *Pinus roxburghii* was the tree species with highest market value of firewood as (NPR. 63,793) (US$ 491) here. Rural stratum had the highest merchantable values for timber class A in *C. camphora*, for total timber in *C. camphora*, for firewood in *Eucalyptus camaldulensis* and for total wood in *C. camphora* while the urban stratum had the highest merchantable value for timber class B in *C. camphora*.

Economically, *C. camphora*, recorded from 86 plots and *P. roxburghii* recorded from 30 plots showed the highest merchantable timber and firewood values respectively in the study area. 32 timber class A and 49 timber class B logs of *C. camphora* were estimated from the study sites. *C. camphora* was second highest expensive species, the retail market prices of which varied from NPR 2200 to 3200. *E. camaldulensis*, *S. cumini* and *F. floribunda* were other tree species with more economic valuations. Local merchantable market prices matter during valuation because they vary for a single species.

Table 6: Market values (MV) of merchantable wood i.e., timber plus firewood from trees outside forest along the urban-rural gradient in Kathmandu valley, Nepal. Market values of timber of class A and B, total timber, firewood and total wood in NPR and US$

Strata	MV of timber class A (NPR ha^{-1})	US$	MV of timber class B (NPR ha^{-1})	US$	MV of total timber (NPR ha^{-1})	US$	MV of firewood (NPR ha^{-1})	US$	MV of total wood (NPR ha^{-1})	US$
Urban	698,567	5,382	108,255	834	806,821	6,216	488,709	3,765	1,295,531	9,981
Suburban	383,485	2,954	60,759	468	444,244	3,423	444,104	3,421	888,828	6,848
Rural	789,871	6,085	80,539	620	870,410	6,706	380,303	2,930	1,250,713	9,636

Table 7: Tree species and their market values (MV) of timber class A, timber class B, total timber, fire wood and the total wood in different strata of the study area

Strata	Species	MV of timber class A (NPR ha^{-1})	US$	Species	MV of timber class B (NPR ha^{-1})	US$	Species	MV of total timber (NPR ha^{-1})	US$	Species	MV of firewood (NPR ha^{-1})	US$	Species	MV of total wood (NPR ha^{-1})	US$
Urban	*Cinnamomum camphora*	218,142	1,681	*Cinnamomum camphora*	31,077	239	*Cinnamomum camphora*	249,219	1,920	*Pinus roxburghii*	86,736	668	*Cinnamomum camphora*	315,156	2,428
Suburban	*Eucalyptus camaldulensis*	116,498	898	*Syzigium cumini*	16,069	124	*Eucalyptus camaldulensis*	120,125	925	*Pinus roxburghii*	91,760	707	*Syzigium cumini*	175,826	1,355
Rural	*Cinnamomum camphora*	530,006	4,083	*Fraxinus floribunda*	15,196	117	*Cinnamomum camphora*	543,055	4,184	*Eucalyptus camaldulensis*	92,461	712	*Cinnamomum camphora*	591,656	4,558

Discussion

A total of 150 plant species were reported from the study area (Table 2). Vakhlamova *et al.* (2014) found slightly high species richness (160) in urban–rural gradient in Kazakhstan. It might be due to enumeration of all vascular plants regardless of DBH in the study. Moreover, Thompson (2010) found comparatively less species diversity (22) from in Khartoum, Sudan. It is possibly due to enumeration of only the living fences in the urban and suburban gardens where homogeneity of species occurs. Species richness in terms of stratum area (ha^{-1}) was higher in rural stratum than in urban and suburban strata (Table 1). Vakhlamova *et al*. (2014) also found an increasing trend of species richness from urban to rural in urban–rural gradient in Kazakhstan, Western Siberia. This pattern can be explained by the fact that plant life forms and evolutionary strategies do not follow any urban-rural gradient, rather are affected by varied habitat and landscape features. In addition, reduced suitable habitats for plants in densely built-up urban areas and excessive trampling of vegetated patches might cause decrease in plant diversity (Aronson *et al*., 2014). Average species richness (ha^{-1}) was higher in urban stratum than in suburban and rural strata which are due to trees were planted types in the urban stratum while majority of them were natural woodlots in remaining strata.

Tree density in the present study area was found higher than that in TOF in Morang (15 ha^{-1}) (DFRS, 2007) and Nawalparasi (10 ha^{-1}) districts (Kharal *et al*., 2008) which might be due to dominance of agricultural lands and less tree plantation culture in Terai area. The average tree density was found more in suburban stratum than in urban and rural strata which is due to abundance of trees with 20-29.9 stem diameter class indicating more branched trees here.

The higher average tree density in urban stratum than in rural in this study (Table 3) showed the similar patterns in Morang and Nawalparasi districts (DFRS, 2007; Kharal *et al*., 2008) This pattern could be due to plantation drives (also includes exotic species) during Panchayat regime in the urban areas in Kathmandu valley and major other urban areas (Goutam, 2018). Moreover, rural people cut down the trees for domestic use. The average trees heights and average DBH also followed the same distribution pattern (DFRS, 2007 and Kharal *et al*., 2008).

Average density of tree quality class A and B were found more in urban stratum than in suburban and rural strata whereas that of tree quality class C was found more in rural stratum than in suburban and urban strata (Table 4). This is supported by the occurrence of more average stem density and distribution of mature trees (≥30) in the urban stratum. This is due to more abundance of such mature trees *Eucalyptus camaldulensis*, *Ficus elastica*, *Jacaranda mimosifolia* etc.) in the parks, roads, river and stream lines etc. whereas due to less dominance of such sized trees, rural stratum had less average tree density with dominance of smaller stem diameter class. Furthermore, both tallest tree and widest tree were also recorded in urban stratum.

Out of four stem diameter classes, dominance of smaller diameter class (5-9.90 cm and 10-19.90 cm) in the urban stratum in the study area (Table 4) is similar as Morgenroth *et al*. (2020) reported in America's urban forests as > 40% of trees in the smallest DBH class (< 15 cm) which could be attributed to preference for smaller ornamental trees as Bottle brush, Albizia, Junipers etc. in urban areas or a recent increase in tree planting efforts. A greater proportion of stem diameter classes of 10-19.9 cm and ≥ 30 cm in urban stratum were also same as Morgenroth *et al*. (2020) found the dominance of 16–45 cm DBH class in urban forests. This may be due to existence of youthful trees. As regards the stem densities of diameter classes 5-9.90 cm, 10-19.90 cm, 20-29.90 cm and ≥ 30 cm in Kathmandu valley, values are higher than those reported from Morang (DFRS, 2007) and Nawalparasi (Kharal *et al.*, 2008); that could be attributed to less planted trees in both Morang district and Nawalparasi district. Further, stem density of lower diameter class (5-9.90 cm) was higher in rural stratum than that in suburban and urban strata whereas stem densities of higher diameters were higher in urban and suburban strata except for trees of diameter 20-29.9 cm which showed uneven distribution. This result is consistent with the findings reported from Morang district (DFRS, 2007), but different from that reported from Nawalparasi district (Kharal *et al*., 2008). This could be due to more naturally regenerated trees in rural stratum in both Morang and the study area. Also, tree plantation drive earlier during Rana regime and Panchayat regime would have contributed to this pattern of tree size class distribution (Goutam, 2018).

TOF are important in terms of wood production. DFRS (2015), on the basis of FAO recommendation, has stated that 13.29% of middle mountains forests have the potential of timber production. This study shows slightly higher value (14.38%) of timber production by TOF. Similar results are found in India (FSI, 2011; Ghosh & Sinha, 2018) as well as in Kerala, India (Krishnankutty *et al*., 2008). But Yadav *et al*. (2020) reported higher percentage of timber production (25.17%) from TOF in Dhangadhi Municipality, Siraha district, Nepal which is due to more distribution of planted tree species with wider DBH there.

In a study by Bembenek *et al*. (2014), high mean tree height, mean DBH and high mean volume of merchantable timber with low mean tree density of Scots pine were reported. The higher volumes of merchantable timbers of class A and class B in the urban stratum than in rural and suburban strata in the study area could be due to distribution of more mature and taller trees. It might be due to conservation of the old trees in the parks, road sides, river lines, pond lines, etc. Similarly, lower volumes of merchantable timbers of class A and class B in the rural stratum might be due to lesser tree density as well as less dominance of stem density of ≥ 30 diameter class.

Conclusions

Urban TOF are important in terms of species diversity whereas suburban TOF are richer in terms of density. Due to the presence of large sized tree species planted during Rana regime, urban TOF have taller and wider trees. Due to more tree density of timber class A and class B in urban stratum, volumes of total merchantable timber along with timber class A and class B and biomass of merchantable firewood were also found higher here. Rural TOF are economically more important. Due to high market prices of the wood of tree species recorded in rural stratum, market value of timber class A and total timber were found higher in rural stratum than the others. Urban TOF are also economically important because it showed high market value for B class timber, firewood and total wood. In terms of TOF species, *C. camphora* and *P. roxburghii* were found to be economically more important as they showed the highest merchantable timber and firewood values. People should be encouraged for afforestation in TOF areas with these species which offers opportunity of timber availability and could help in local livelihood. On the other hand, import of wood and wooden materials could be minimized as well as urban greenery would be enhanced.

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