PLANT SPECIES DIVERSITY AND BIOMASS IN THE FORESTS OF MORANG DISTRICT, EAST NEPAL

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

PRAMILA KUMARI GACHHADAR

AUGUST, 2024

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DEAN'S OFFICE

Kirtipur, Kathmandu, Nepal

Reference No.:

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EXAMINERS

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DECLARATION

Thesis entitled "**Plant Species Diversity and Biomass in the Forests of Morang District, east Nepal"** 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 Associate Prof. Dr. Chitra Bahadur Baniya of Central Department of Botany, Tribhuvan University and co-supervised by Prof. Dr.Tej Narayan Mandal of Degree Campus, Biratnagar, Tribhuvan University, 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.

.....

Pramila Kumari Gachhadar

RECOMMENDATION

This is to recommend that **Ms. Pramila Kumari Gachhadar** has carried out research entitled **"Plant Species Diversity and Biomass in the Forests of Morang District, east Nepal"** 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

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On the recommendation of **Associate Prof. Dr. Chitra Bahadur Baniya** (Central Department of Botany, Tribhuvan University, Kirtipur) and **Prof. Dr. Tej Narayan Mandal** (Department of Botany, Degree campus, Biratnagar, T.U., Nepal), this Ph. D. thesis submitted by **Ms. Pramila Kumari Gachhadar** entitled **"Plant Species Diversity and Biomass in the Forests of Morang District, east Nepal"** is forwarded by Central Department Research Committee (CDRC) to the Dean, IoST, T.U..

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.....

Pramila Kumari Gachhadar

August, 2024

शोध सार

उष्णकटिबंधीय वन पारिस्थितिक प्रणाली महत्त्वपूर्ण छ, किनभने यसले कार्बन भण्डारको रूपमा काम गर्दछ । प्रजाति संरचना, जैविक विविधता (Biodiversity), र जैविक पिण्ड (Biomass) बढ्दो उचाइसँगै परिवर्तन हुने गर्दछ । यो अध्ययनको उद्देश्य माटोको विशेषतामा हुने भिन्नता र वनमा रहेका प्रजातिहरूको संरचना, विविधता, जैविक पदार्थ, कार्बन र पोषक तत्वको भण्डारमा प्रभावको अध्ययन हो, जसको लागि मोरङ जिल्लामा भाउने (२०० मिटर), राजा-रानी (५०० मिटर), मुरचुङ्गी (८०० मिटर), अधेरी (१००० मि.) र साग्मा वन (१२०० मि.) गरी पाँच वटा वन छनोट गरिएको थियो, जुन सामुदायिक बन अन्तर्गत पर्दछ । ५० नमूना प्लटहरू, प्रत्येक वनबाट १० प्लटहरू अनियमित ढांचा अनुसार रूख (Trees) को लागि नमूना आकार २० मि. x २० मि., बुट्यानहरू (Shrubs) को लागि ५ मि.x ५ मि. र साना झाडीहरू (Herbs) को लागि १ मि.x १ मि. थियो । माटो १० से.मि. x १० से.मि. x ३० से.मि. को मोनोलिथद्वारा संकलन गरिएको थियो, जुन मसिना जरा सङ्कलनका लागि पनि प्रयोग गरिएको गरिएको थियो ।

कुल प्रजातिहरू, बुट्यान र साना झाडी प्रजातिहरू बढ्दो उचाइको साथ सांख्यिकीय रूपमा महत्त्वपूर्ण बढ्दो ढाँचा देखायो र रूख प्रजातिहरू बढ्दो उचाइसँगै गिरावट प्रवृत्ति देखाएको छ । कुल जैविक पिण्ड (Total stand biomass) र रूख जैविक पिण्ड (Tree biomass) ले सांख्यिकीय रूपमा महत्त्वपूर्ण रूपमा घटेको सम्बन्ध देखाएको छ, जबकि बुट्यान जैविक पिण्ड (Shrub biomass) र झाडी प्रजातिको जैविक पिण्ड (Herb biomass) ले बढेको ढाँचा देखायो । Important Value Index को आधारमा, साल (*Shorea robusta*) तलको चारवटा जंगलहरुमा र चिलाउने (*Schima wallichii*) साग्मा (माथिल्लो) वनमा प्रभुत्व छ । सोरेन्सेनको रुखको समानता सूचकाङ्कले मुरचुङ्गी (८०० मि.) र

अधेरी जंगल (१००० मि.) बीच ६४ प्रतिशत समानता देखाएको छ । जबकि भाउन्ने (२०० मि.) र साग्मा वन (१२०० मि.) बीच कम समानता (२२%) प्रदर्शन गरिएको थियो । कूल वनस्पतिमा अधिकतम जैविक पिण्ड, ८१५.८८ Mg ha^{-1} र कार्बन स्टक, ३३३.६३ Mg C ha^{-1} भाउन्ने बनमा पाइयो भने न्यूनतम बायोमास, २९९.९६ Mgha^{-1} र कार्बन स्टक, १४०.१९ Mg C ha^{-1} साग्मा वनमा पाइयो । पातपतिंगर ७.१ Mg ha^{-1} र २५.७ Mgha^{-1} को बीचमा पाइयो । मसिनो जराको जैविक पिण्ड (Fine root biomass) ७.१४ Mg ha^{-1} देखि १६.० Mg ha^{-1} सम्म, भाउने जंगलमा न्यूनतम र मुर्चुङ्गी वनमा अधिकतम पाइयो । २ मि.मी. व्यास भएको जराले अधिकतम र २-५ मि.मी.ब्यास भएको जराले कम बायोमास देखायो ।

माटोको आर्द्रता ८.४८ % र २१.२९ %, पानी धारण क्षमता ६८.२१ देखि ९७.४८ %, pH ५.०६ देखि ५.६८ , जैविक कार्बन १.२० % देखि ३.०४ %, कुल नाइट्रोजन ०.१२ % देखि ०.२६ % सम्म पाइयो । भाउने वनमा अधिकतम माटोको आर्द्रता, जैविक कार्बन र कुल नाइट्रोजन रहेको थियो, जसले पारिस्थितिक प्रणालीको लागि स्वस्थ अवस्थालाई जनाउछ । माटोको आर्द्रता र मसिना जरा बायोमासले रूख प्रजातिहरूको वृद्धिको लागि सबैभन्दा महत्त्वपूर्ण रहेको पाइयो । त्यसैगरी, उचाइ, आर्द्रता, र गैर-पात लिटरमास झाडी प्रजातिहरूको लागि महत्त्वपूर्ण थियो। कुल नाइट्रोजन र पात लिटरमास झाडी प्रजातिहरूको लागि महत्त्वपूर्ण पाइयो । अन्तमा, उचाइको भिन्नताले माटोको गुण, बिरुवाको घनत्व, बिरुवाको विविधता, जैविक पिण्ड, कार्बन र पोषक तत्वको भण्डारमा प्रभाव पार्छ जुन एक अर्कामा निर्भर हुन्छ । वर्तमान अध्ययनका निष्कर्षहरूले कार्बन उत्सर्जनलाई न्यूनीकरण गर्न, उर्बर र उत्पादक वन व्यवस्थापनको रणनीति बनाउन मद्दत पुग्नेछ ।

मुख्य शब्दहरू: *उष्णकटिबंधीय वन - माटो गुणहरू - प्रजाति संख्या – पातपतिंगर - कार्बन स्टक - मसिना जरा*

ABSTRACT

Tropical forest ecosystem is crucial for mitigating the effects of climate change, because it acts as a carbon sink. Additionally, forest is the home to a significant portion of world's biodiversity. Species composition, diversity, and biomass thought to be changed along the increasing elevation. The objective of the present study was to determine the variation in soil characteristics and their effect on species composition, diversity, biomass, carbon and nutrient stocks in the forests located along elevation gradient in Morang district of east Nepal.

Five forest sites located at different elevations were selected which are addressed here as Bhaunne (200 m), Raja-Rani (500 m), Murchungi (800 m), Adheri (1000 m) and Sagma (1200 m), which lie inside the five different community forests in Morang district. A total of 50 sampling plots, 10 from each forests were laid randomly. Sampling size for tree was 20 m x 20 m, for shrubs nested 5m x 5m and for herbs nested 1m x 1m. Soil was collected by soil monolith of 10 cm x 10 cm x 30 cm, which was also used for fine root collection and litter mass was collected by using 1 m x 1 m sampling size within the plots used for tree sampling. Trees (≥10 cm girth) biomass and shrubs biomass was estimated by girth: biomass allometric equation. Herb biomass was estimated by harvest method. The carbon content of each plant components were estimated by ash content method. The data were analyzed by MS excel and R-package.

Plot wise generalized linear model up to first order showed that the total species richness, herbs species richness and shrub species richness statistically significantly inclined and tree species richness statistically significantly declined pattern with increasing elevation. Total biomass and tree biomass showed declined relationship with elevations. While, shrub biomass showed statistically not significant inclined pattern and herb biomass showed statistically significant inclined pattern with increasing elevation.

Shorea robusta was a dominant tree species with the highest Important Value Index value in the four forests except Sagma. *Schima wallichii* was the dominant species with the highest IVI in Sagma. Sorensen's similarity index of trees revealed 64% similarity between Murchungi and Adheri forests, while lower similarity (22%) was

exhibited between Bhaunne (extreme lower elevation) and Sagma forest (extreme high elevation).

Stand biomass (815.88 Mg ha^{-1}) and carbon stock (333.63 Mg C ha^{-1}) were maximum in lower elevation forest (Bhaunne), while minimum biomass (299.96 Mg ha^{-1}) and carbon stock (140.19 Mg C ha^{-1}) were found in higher elevation forest (Sagma). Litter mass ranged between 7.1 Mg ha^{-1} and 25.7 Mg ha^{-1} showing irregular trend even in carbon and nutrient stock (N, P, K) due to irregular variation in non–leaf (wood) component of litter mass. Leaf litter exhibited close C: N ratio than non-leaf (wood) litter indicating a fast decomposition and nutrient release in the ecosystem. Fine root biomass ranged from 7.14 Mg ha^{-1} to 16.0 Mg ha^{-1}. Carbon and nutrient stocks in fine root followed the same trend as per the trend in biomass. Fine root of <2 mm diameter size contained higher biomass than 2-5 mm size. Further, C: N ratio in <2 mm size was narrow than 2-5 mm size which is expected to release more nutrients in the ecosystem.

Soil moisture ranged between 8.48 % and 21.29 %, water holding capacity from 68.21 to 97.48%, pH from 5.06 to 5.68, organic carbon from 1.20% to 3.04%, total nitrogen from 0.12 to 0.26% in different forests located along the different elevations. The lower elevation forest (Bhaunne) contained maximum soil moisture, organic carbon and total nitrogen, representing a healthy condition for the ecosystem. The soil moisture and fine root biomass were the most significant predictors for the tree species richness. Similarly, elevation, moisture, and non-leaf litter mass were significant for shrub species richness (Elev: $p < 0.01$, Moist1: $p < 0.01$, NLP: $p < 0.05$). The total nitrogen and leaf litter mass were important for herb species richness with p values; < 0.001 and < 0.01 respectively. In conclusion, variation in elevation has the effect on change in soil properties, plant density, plant diversity, biomass, carbon and nutrient stocks which accumulate in interdependent way. Findings of the present study may help to formulate a strategy for the management of productive forest to mitigate the carbon emission.

Keywords: *Tropical forest - Soil properties - Species richness - Litter mass - Carbon stock - Fine root*

LIST OF ACRONYMS AND ABBREVIATIONS

BA	:Basal Area
BD	:Bulk Density
BD1	:Bulk Density at 0-15 cm Soil Depth
BD2	:Bulk Density at 15-30 cm Soil Depth
Cla	:Clay
Cla1	:Clay at 0-15cm Soil Depth
Cla2	:Clay at 15-30 cm Soil Depth
D	:Density
DCA	:Detrended Correspondence Analysis
Elev	:Elevation
Elev	:Elevation
F	:Frequency
FR125	:Fine Root of 2-5mm Diameter Sized at 0-15cm Soil Depth
FR1P25	:Phosphorous of 2-5mm Diameter size Fine Root at Upper Soil Depth (0-15cm).
FR2Kle2	:Amount of Potassium of Less than 2 mm Diameter Size Fine Root at Lower Soil Depth (15-30cm)
G	:Gram
GBH/gbh	:Girth at Breast Height
Ha	:Hectares
Hsp	:Herb Species
IVI	:Important Value Index

K	:Potassium
K1	:Potassium at 0-15 cm Soil Depth
K2	:Potassium at 15-30 cm Soil Depth
Kg	:Kilo Gram
LK	:Amount of Potassium in Leaf Litter Mass
m asl	:Mean above sea level
Mg	:Milligram
Mg	:Mega Gram (1 Mg = 1000 Kg)
Mois	:Moisture
Mois1	:Moisture at 0-15 cm Soil Depth
Mois2	:Moisture at 15-30 cm Soil Depth
MTFR	:Mean Total Fine Root
NLP	:Amount of Phosphorous in Non-Leaf Litter mass
OC	:Organic Carbon
OC1	:Organic Carbon at 0-15 cm Soil Depth
OC2	:Organic Carbon at 15-30 cm Soil Depth
OM	:Organic Matter
OM1	:Organic Matter at 0-15 cm Soil Depth
OM2	:Organic Matter at 15-30 cm Soil Depth
P	:Phosphorous
P1	:Phosphorous at 0-15cm Soil Depth
P2	:Phosphorous at 15-30cm Soil Depth
Pg	:Petagram (1 Pg = 1×10^{12} Kg)
Ph	:Percentage of Hydrogen ion

pH1 :Percentage of Hydrogen ion at 0-15 cm Soil Depth

pH2 :Percentage of Hydrogen ion at 15-30 cm Soil Depth

Por :Porosity

Por1 :Porosity at 0-15 cm Soil Depth

Por2 :Porosity at 15-30 cm Soil Depth

RD :Relative Density

RDA :Redundancy Analysis

San :Sand

San1 :Sand at 0-15 cm Soil Depth

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FIELD PHOTOS

CHAPTER 1

1. INTRODUCTION

1.1 Background

Globally, the forests cover 31% of the total land area. Approximately half of the total forest is relatively disturbed and more than one-third is naturally regenerated. The total forest area is 4.06 billion hectares including.1.11 billion hectares of primary forest. Tropical forests account 45 % and subtropical forests occupy 11 % of the world's forest area (FAO, 2010; FAO, 2020).

Forest ecosystem provides a lot of services to environment and society. Towards environment, it functions as natural carbon sink as huge carbon pools are stored in vegetation along with soil (Lugo & Brown, 1992). As a carbon sink it helps to mitigate the carbon emission to reduce the effect of climate change (IPCC, 2023). On the other hand, forest ecosystem acts as repository for biodiversity which provides various services for the benefits of society (Gibbs *et al*., 2007; Daba *et al*., 2022; CBD, 1992; HMGN, 2002).

Globally, there has been a great deal of research on the functions of tropical forests in reducing climate change and the possible consequences that deforestation may have on the climate (Grace *et al*., 2006). The amount of carbon flow caused by the destruction of tropical forests is less known (Brown & Lugo, 1984). The significant capacity of tropical forests to cycle and storage of carbon has seriously been questioned. Tropical forest has been rapidly fragmented due to agricultural development (Ordway & Asner, 2020).

The primary abiotic elements that might alter forest carbon stocks include climatic variables such as temperature and precipitation; topographic variables such as elevation and slope and soil variables such as pH, moisture, bulk density, texture etc. Soil properties and vegetation of the tropical forests influence the forest carbon dynamics (Mitchard, 2018; Grinand *et al*., 2019).

Nepal is a mountainous country with the sharp variation in elevation which resulted into different biophysical diversity (TISC, 2002). Nepal is divided into five physiographic regions: Tarai, Churia (Siwaliks), Middle Mountain, High Mountain, and High Himal based on geology and geomorphology (LRMP, 1986). Tarai and

Churia (Siwaliks) come under the tropical region in Nepal. While subtropical regions start from the upper part of Siwaliks. Siwaliks run entire lenghth of the sourthern part of Nepal, north to Tarai. Tropical regions in Nepal vary in elevations. Tarai covers 13.7% of the total land area and occupies 6.9% of the total forest. Siwaliks occupy 12.8 % of the total land area and occupy 23.04 % of the total forest cover of Nepal (DFRS, 2015).

Siwaliks (Churia) are the youngest mountain range in the Himalaya. This region is highly erosive and flexible (Hagen, 1998). Tarai and Siwalik region are generally occupied by Sal forests. Siwaliks of eastern Nepal are the suitable habitat to a number of people. In the last 50 years, the eastern Siwalik forest of Nepal has been shrinking by 23% (150 km^2) (Bhuju *et al*., 2007). The Siwalik has a wider range of climate and vegetation, although little is known about its biodiversity. Due to favorable climatic conditions, tropical forests are known for their high diversity and standing biomass (Pathak & Baniya, 2016).

Characteristic of the lowland Tarai is the *Shorea* forest, which is home to plants including *Lagerstroemia parviflora* Roxb., *Syzygium cumini* (L.) Skeels, *Careya arborea* Roxb., *Adina cordifolia* (Roxb.) Brandis, and *Terminalia alata* Heyne ex Roth. Lowland Sal forests provide ideal habitat for trees, shrubs, herbs, climbers, and ferns, and they also meet local subsistence requirements (Gautam & Devoe, 2006). Their growth pattern varies with elevation. The variation in elevation means there are also variation in the temperature, humidity, light intensity, and rainfall that alter the type and functioning of forest (Chen & Brassard, 2013). The ecological distribution of forest types in mountainous areas is also significantly impacted by the elevation (Wei *et al*., 2015).

Therefore, it is highly essential to study the plant species diversity, community structure, biomass and carbon stock along with the soils properties of tropical – subtropical forest of eastern Nepal.

1.2 Species composition and diversity

Composition, structure, and function are the three primary elements that have strong relationship and make up biodiversity (Sahu *et al*., 2008). The stability and sustainability of forest communities are expressed by an evaluation of species diversity indices (Sarkar & Devi, 2014). A large fraction of the world's biodiversity is

found in the forests (Baraloto *et al*., 2013; Naidu & Kumar, 2016). Due to their adaptability and abundance in natural resources, forests themselves have generated a wide range of advantages and services for the economy, society, environment, and culture. The species composition, diversity, species richness, distribution pattern, and function, which are assumed to be changing through time (Manral *et al*., 2018; Naidu & Kumar, 2016) are necessary for the ecosystem services.

The elevation, soil, climate, and geographic location of the region, all have an impact on the plant species composition and their distribution in the forest ecosystems. Due to altitudinal variation there is variation in temperature and rainfall and consequently the floristic pattern becomes very diverse (Chandra *et al*., 2016; Ismaeel *et al*., 2024).

A decline in species richness was seen as elevation increased on a mountain in a terrestrial environment (Singh *et al*., 2015). Several plant species, particularly the climber, parasite, and tree may respond to climate. In comparison to species with higher growth forms like trees and shrubs species, the lower growth forms like herbs, climbers, epiphytes, pteridophytes, and bryophytes may react more swiftly.

The elevational diversity pattern is one of the most widely recognized trends and states that species diversity tends to be lower on mountain tops than it is at lower elevations (Berhanu *et al*., 2017; Lazarina *et al*., 2019). Species richness in any forest depends on the severity, variation, and predictability of the environment in which it grows (Slobodkin & Sanders, 1969). Therefore, diversity tends to increase if the environment becomes more favorable and predictable (Putman, 1994). The physiographic factors are widely known to show a major impact on plant microhabitats, especially in hill-slope form (Sharma *et al*., 2010).

The temperature regime of each place is greatly influenced by its elevation and slope. Along the elevation, the geographic and climatic conditions change sharply. At extreme elevations, just one or two living forms remain as the diversity of life-forms typically declines with elevation. Thus, elevation is made up of a complex network of interconnected climatic factors that are highly associated with a wide range of other environmental characteristics (Kharkwal *et al*., 2005). These influence on the distribution, growth form, forest composition and structure of species on a variety of ecosystem (Sharma *et al*., 2010).

Shorensen's similarity index estimation has the scope to show the extents of similarity among different forests. Variation in elevations may cause variation in microclimatic conditions which finally reflects in the pattern of diversity and distribution of plant species (Macek *et al*., 2019; Murakami *et al*., 2022). Biological diversity is lost as a result of the poor management of natural resources. The global storage capacity of forests is enormous, with 398 Pg C held in forest soils and 360 Pg C (1 Pg = 1015 g) in the form of live and dead biomass components. Additionally, the forest ecosystem sequesters around 1.7 ± 0.5 Pg C per year (Houghton & Goetz, 2008; Kaushal & Baishya, 2021). Reviewing the literature on species richness and elevation gradients, it was found that 25% of studies show a monotonic decline in species richness from low elevation to high elevation, 50% show a hump trend in species richness with a maximum species at mid-elevation, and the remaining studies depict a nearly constant species richness from the lowlands to mid-elevation and a strong decline further (Rahbek, 2006). While some studies have identified a declining trend in species richness with elevation (Zhan *et al*., 2023). Further, Vetaas & Grytnes (2002) revealed highest species richness for vascular plants in 1500-2500 m elevations. According to Liang *et al*. (2007), three main components of biodiversity can be identified as: (i) composition, (ii) structure, and (iii) function. Due to favorable climatic conditions, tropical forests are known for their tremendous variety of species (Pathak & Baniya, 2016). A characteristic of the lowland Tarai is the *Shorea* forest, which is home to plants including *Lagerstroemia parviflora, Syzygium cumini, Carea arborea*, *Adina cardifolia,* and *Terminilia alata*. Lowland Sal forests provide suitable habitat for trees, shrubs, herbs, climbers, and ferns, and they fulfill local livelihood necessities.

1.3 Plant biomass and carbon stock

The concept of biomass in the context of forests, refers to the carbon that trees store or trap. This carbon is an essential part of the carbon pools in terrestrial ecosystems. These pools consist of soil organic matter, woody debris, litter, aboveground biomass, and belowground biomass. The Intergovernmental Panel on Climate Change (IPCC) has identified these pools as the primary carbon pool (Vashum & Jayakumar, 2012; IPCC, 2013; IPCC, 2023).

Standing crop biomass is the total quantity of accumulated organic matter in the vegetation present in a region at any one time, whereas productivity is the rate at

which organic matter is produced by photosynthesis. The past ten years have seen the beginning of a precise estimate of the biomass stocks and net primary production of moist tropical forests. Forest biomass is a complicated property impacted by species composition, forest structure, distribution, and biological processes (Hu *et al*., 2021). The global carbon cycle, carbon stocks, and biomass are all significantly influenced by the forest environment and it varies along with the gradient in elevation (Saeed, *et al*., 2019).

Tropical forests comprise 34% of the terrestrial gross primary production and contain approximately 55 % of the world's forest carbon (Beer *et al*., 2010; Pan *et al*., 2011). In forests, carbon is mostly stored in soils and biomass. Tropical forests' biomass and rates of biomass accumulation have been shifting throughout time as a result of human disturbances & natural disasters (Lugo & Brown, 1992).

Aboveground biomass accounts for 60% of all phytomass and is regarded as a key factor in the analysis of the plant carbon pool (Houghton *et al*., 2009; Pan *et al*., 2011). In order to account for the total carbon sequestered by the vegetation over a specific time, it is also necessary to assess other biomass components, such as belowground biomass, dead wood biomass, and litter biomass. The root biomass typically accounts for 20% of the total vegetative biomass in temperate terrestrial forests (Jackson *et al*., 1996). A significant amount of carbon (C) consumed by plants during photosynthesis is transmitted to roots and associated symbionts, may be even exceeding the quantity given to aboveground components (Litton *et al*., 2007; Leuschner *et al*., 2011; Mccormack & Guo, 2014). Forest serves as a storehouse for biodiversity and a carbon sink (Gibbs *et al*., 2007), consequently, forest ecosystems have a special role in the reduction of the effect of global scenario of climate change.

The primary element of forest ecosystems involves the soil organic carbon (SOC) which constitutes a dynamic role in forest functioning (Kumar *et al*., 2016). The carbon is released to the soil as the plant perishes or the plant matter breaks down. Through the degradation of plant biomass and respiration, particularly the respiration of plant roots and the soil, this carbon content can be released as CO_2.

The accurate estimation of forest carbon is necessary to comprehend the function of the forest for mitigating actions to fulfill the National Determined Commitment (NDC), such as REDD+ (Ahmad *et al*., 2018), as well as to assess the function of

forests for their ecosystem services to the underprivileged people. The most significant determinants of carbon sequestration among a number of variables are plant type and species composition. The greatest variety of plant species are found in tropical and subtropical forests (Bogale *et al*., 2017). Researchers have often shown a positive correlation between carbon stock and variety of the plant species in tropical forest ecosystems (Strassburg *et al*., 2010). Species composition and vegetation structure have an effect on the carbon density of forest biomass (Hu *et al*., 2021). The relationship between plant diversity and ecosystem function, in particular C dynamics, has recently drawn significant attention for reducing the effects of climate change (Liang *et al*., 2007; Midgley *et al*., 2010). Thus, research is necessary to evaluate the connection between species diversity and carbon stocks at both local and regional scales (Midgley *et al*., 2010; Strassburg *et al*., 2010).

1.4 Littermass: Aboveground source of soil organic matter

Litter is the term used to describe plant parts that have fallen to the ground, in the form of leaves, bark, needles, and twigs and deposited on the soil surface as littermass. In forests, aboveground litter plays a crucial role to contribute the flow of carbon and nutrients in to the soil. Amount of leaves that fall is strongly influenced by the climate, topography, species composition, and soil fertility (Mccormack & Guo, 2014). The transfer of nutrients and energy from litter mass to the soil is a key mechanism of nutrient recycling since the majority of organic matter (OM) produced by plants is returned to the soil through litter.

Each form of plant litter that is dropped can vary in its composition of both organic chemical components and inorganic nutrients. Density, basal area, age structure, seasons, and elevation all have a significant impact on litterfall dynamics in forest ecosystems (Sundarapandian & Swamy, 1999). The altitudinal variation affects the microclimate and the actions of microorganisms that slow down or speed up the turnover of leaf litter. Decomposition mechanism plays a significant part in the cycling of these nutrients by transforming complex organic molecules into simple forms that plants may use for healthy growth and development (Saha *et al*., 2016).

Ecologists have thus focused on litter because it affects ecosystem dynamics, which determines ecological productivity, and it helps to predict soil fertility (Guendehou *et al*., 2014). Litter decomposition is influenced by three elements: decomposer

communities, litter chemistry that reflect relative differences in litter species decomposability and environmental conditions such soil microclimate (Hättenschwiler *et al*., 2005). Understory vegetation improves the amount of soil organic matter (Furusawa & Kaneko, 2003), the availability of soil nutrients (Nilsson & Wardle, 2005), and the variety of soil organisms (Zhao *et al*., 2012) in the area around it.

Litter mass loss or decay is the result of both the release of carbon dioxide and the discharge of compounds containing both carbon and nutrients (Weil & Brady, 2017). The diversity of the litter also affects the activity of soil organisms and decomposition processes (Baumann *et al*., 2011). Additionally, the chemical properties of the litter components, such as lignin, polyphenol, cellulose, and hemicelluloses, as well as the C: N ratio, have an impact on the rate of decomposition (Silveira *et al*., 2013). During decomposition N concentration decrease over time, a litter with a higher N concentration often exhibits a higher mass loss. Lignin and lignin-like substances have long been thought to slow down decomposition because of their high carbon concentration making wide C: N ratio (Fogel & Cromack, 1977). Litter aids in incorporating carbon and nutrients from plants into the soil, therefore, litter plays an important role in the interaction between plants and soil (Yang *et al*., 2005).

The primary ecosystem activities, which are fueled by the decomposition of plant litter, are the cycling of carbon and nutrients (Cornwell *et al*., 2008). The quantity and quality of litter and the qualities of the soil are crucial for maintaining a healthy ecosystem as well as for the functioning of the forest ecosystem (Zhang *et al*., 2014)). Nutrient release, net immobilization, and net release are the three primary phases that decomposing leaves go through in tropical forests (Vitousek & Sanford, 1986). In addition, there is variation in litter production in different ecosystems depending on the composition of tree species, stand structure, soil fertility, height, latitude, and climate (Becker *et al*., 2015; Parsons *et al*., 2014).

1.5 Fine root: Belowground source of soil organic matter

The fine root is active part of plant that plays a crucial role in a plant's ability to absorb water and nutrients, and it also controls growth by secreting a number of hormones (Domenicano *et al*., 2011). Fine root less than 2 mm in diameter size has short lifespan and high turnover rate because of having narrow C: N ratio than coarse

root (Guo *et al*., 2008; Chen & Brassard, 2013). Thus, makes it a significant source of carbon and nutrients and their cycling in forest ecosystems (Yang *et al*., 2010; Wang *et al*., 2016; Cai e*t al*., 2019). Removal of aboveground litter mass of the forest has impacts on the fine root's vertical and temporal distribution, particularly on annual production and turnover rate (Chuang *et al*., 2013). A crucial component of the metabolism of forests is nutrient and water intake, which is carried out by fine roots. Fine roots, though less in amount but contribute between 30 and 80% of the total organic carbon to soil due to their quick turnover and decomposition rate (Ruess *et al*., 2003). One-third of the world's net primary output is captured by fine roots, which are sensitive to environmental changes (Du & Wei, 2017).

In tropical forest, soil moisture is a key factor in explaining the fine-root dynamics (Yavitt & Wright, 2001; Metcalfe *et al*., 2008). However, due to their relative inaccessibility, fine root dynamics are one of the least studied aspects of forest ecology. For tropical forests, where fine root biomass and its rates of formation and decomposition are high, fine root dynamics are especially crucial (Silver *et al*., 2005). Fine roots are responsible for absorbing the majority of the water and nutrients needed for vegetative growth, despite making up only 2 to 5% of the overall forest biomass (Olesinski *et al*., 2012). Given the close connections between above- and below-ground ecological processes (Wu *et al*., 2020), fine root biomass refers to the way, plants respond to the distribution of above-ground photosynthetic products as well as the availability of soil-resident resources (Yuan & Chen, 2010; Ma & Chen, 2016).

The dynamics of fine root biomass, carbon storage, and other ecological processes are evaluated in part by stand age (Yuan & Chen, 2012; Anderson-Teixeira *et al*., 2018; Jonsson *et al*., 2020; Hu *et al*., 2021) Fine root biomass is shown to rise with stand development, peak at canopy closure, and subsequently decline or stay (Yuan & Chen, 2010, 2012; Pei *et al*., 2018). Also, changes in fine root biomass with stand type are closely related to species diversity (Zeng *et al*., 2020) and soil characteristics (Cai *et al*., 2019). Species diversity may boost belowground production partitioning to absorb more nutrients and water (Ma & Chen, 2017).

1.6 Soil characteristics

Major components of the land are the soils, which are dynamic systems that produce a variety of functions. These soils provide essential ecosystem services including the

regulation of climate and water, carbon sequestration and nutrient cycling (Adhikari & Hartemink, 2016).

Different environmental factors like slope, aspect, climate, landscape, topography, vegetation and microbial activities influence the composition and qualities of soil. Thus, soil properties are the key aspect in determining the status and distribution of vegetation (Nirola & Jha, 2013). Because plant tissues constitute the primary source of soil organic matter (SOM), vegetation is crucial for the development of soil. The vegetation type affects the factors like pH, texture, nutrient availability, and water-holding capacity (Jonsson *et al*., 2020). Diverse ecosystems have very diverse nutrient availability (Sigdel *et al*., 2015). Soil pH, soil organic matter and water storage capacity vary as per the variation in elevation (Sheikh *et al*., 2009). The variation in pH concentration and functional aspects of soil is also caused by the disturbances (Gautam & Mandal, 2013).

Soil has 1.5–3 times more carbon storage capacity than the atmosphere and plants put together (Goodale *et al*., 2002; Lal, 2004; Lehmann & Kleber, 2015). The majority of the carbon in soil is organic carbon (C), which comes from living things and has been preserved for a very long time in deeper soil layers below 20 cm (Fontaine *et al*., 2007).

The main physical characteristics of soil are texture, structure, color, horizonation, consistence, density, porosity, aeration, water retention, and movement (http://www.nrcs.usda.gov). Soil physical characteristics have an impact on the stand, distribution, cover, rate of tree growth, vigor of natural reproduction, and other significant factors (Paudel & Sah, 2003). They also have a significant impact on below-ground carbon storage, nutrient retention, and availability (Silver *et al*., 2000). Likewise, soil chemistry is concerned with the chemical processes that take place in soils, such as the mineralization of macro- and micronutrients. Among the chemical properties, pH, salinity, organic matter content, and the carbon to nitrogen (C: N) ratio are significant chemical characteristics. Soil nutrients are essential for the formation of plant communities and structural diversity in all types of ecosystems. Soil conservation has fundamental significance for biodiversity conservation. Variations in geography, climate, physical weathering processes, cover of vegetation, microbiological activity, and various other biotic and abiotic variables, the

physiochemical characteristics of forest soils varies through time and space (Paudel & Sah 2003; Shameem & Kangroo, 2011; Gairola *et al*., 2012).

High elevation lowers the temperature due to reduced atmospheric pressure, exhibits variation in precipitation and stress in soil nutrients; consequently, these factors have a significant impact on the states of biodiversity (Wang *et al*., 2020). Soil nutrients are crucial for the development of plant communities, species, and structural variation in tropical forest ecosystems (Theodose & Bowman, 1997). Soils serve as both source and sink of CO_2. Soils retain large amount of organic carbon, twice more than vegetation and two-thirds more than the atmosphere (Lal, 2004; Li *et al*., 2013; Lehmann & Kleber, 2015). Therefore, a strategy to lower the carbon emissions from the soil and to increase carbon sequestration by the vegetation has great potential to improve soil management in tropical community and natural forests in Nepal (Kafle, 2019). Physical, chemical and biological components of soils are therefore very crucial in maintaining structure, functions, stability and dynamics of any ecosystems.

Understanding and identification of natural resources and their biodiversity is highly essential in order to fulfill minimum standard of signatory of convention on biodiversity (CBD, 1992; HMGN, 2002). The eastern part of Nepal which was considered as very rich in terms of composition and endemism, has not been studied so far yet. There are very few studies on biomass and carbon stocks in the forests of Nepal (Mandal, 1999; Baral *et al*., 2009; Bohora *et al*., 2021; Regmi *et al*., 2021). Further, no study has been conducted regarding how the elevational gradient affects in biomass and carbon stock in different forests. In order to fulfil this gap, it is important to know the diversity pattern and variation in plant biomass and carbon stock of herb, shrub and tree species in forest stands located at different elevations.

1.7 Rationale

Nepal has a distict physiography and its Himalayan region contains a wide range of habitats and the greatest elevation difference over a short vertical distance (about 150 km) (Dobremez, 1976).

Several National and international researchers have conducted several studies all over Nepal. They were mainly concentrating on the alpine and subalpine areas of the Nation. All of their studies were focusing on the species richness pattern along a wide range of elevation (100–5500 m, Grau *et al*., 2007; 100-7400 m, Baniya *et al*., 2009).

Similarly, studies focused on species richness and composition in Kanchanjanga, Eastern Nepal were Kandel *et al*. (2019), Chhetri & Shrestha (2019 from 2100 -3000 m. Likewise, Borah *et al*. (2019) studied at alpine region of Eastern Himalaya from 3500m-4500m. Findings of previous studies insights little scientific attention on the biodiversity of low mountains, particularly those in tropical and subtropical areas.

Eastern Nepal is a gateway of monsoon rain in Nepal that causes high biodiversity. It is a major part of eastern Himalaya, one of the hotspots of the world. The old and matured tropical eastern forest of Nepal is a suitable habitat for many endemic plants and animals such as Spiny Babbler, Clouded leopard, Red panda. Thus, the lowland of eastern Nepal (Mai Pokhari- Jalthal) is reported as high biodiversity and endemic species zone (Joshi & Joshi, 2022; Sharma *et al*., 2021).

The present study area is rich in diversity due to moist and humid environment and great variation in the elevations within short latitude. Few researches are carried out in Siwalik range and Charkoshe Jungle of Sunsari district which are concerned to pteridophytes, wetland plants, Orchids and plant diversity and biomass. However, studies regarding the changes in the patterns of plant diversity, plant biomass and carbon storage along the varied elevational zones are quite scanty. Therefore, the present study was taken to address the gap on the species diversity pattern, biomass and carbon stocks including soil characteristics in the less-explored forest areas along elevational gradient in the forests of Morang district, eastern Nepal.

1.8 Hypothesis

The hypotheses proposed for this research are:

- The species richness of plants decreases with an increase in elevation.
- The biomass of plant species decreases with an increase in elevation.
- The biomass of plant species increases with an increase in species richness.
- The magnitude of soil organic carbon and total nitrogen decrease with an increase in elevation.

1.9 General objective

The general objective of the study was to find the status of plant species diversity and their biomass in the forests located at different elevations in Morang District, east Nepal.

The specific objectives

The specific objectives of the present research are:

- To study the plant species composition and pattern of plant diversity among different forests,
- To know the plant biomass and carbon stock among different forests,
- To study the carbon and nutrient stocks (N, P, K) in litter mass, fine root biomass in different forests.
- To know the changes in the physico-chemical properties of soils along different forests.

1.10 Limitations of the study

- The study area only included the tropical and subtropical region of the Eastern Nepal.
- Impact of animal grazing could not be included in the study.
- Epiphytes and pteridophytes were not included in this study.
- Seasons were not concerned during the data collection.

1.11 Outline of the thesis

In the thesis, trees greater than equal to 10 cm girth at breast height were considered as tree. Only herbs, shrubs and trees were considered in this study. **Chapter 1** summarizes the overall introduction of the thesis, the significance of the study, the key objectives, limitation of the study, the thesis outline, and conceptual framework of research work (**Figure 1**). **Chapter 2** contains literature review. **Chapter 3** gives detail information: location, vegetation, and climatic situation of study area. It also contains materials and methods, sampling design and structure used to obtain each objective. **Chapter 4** includes overall results and discussions of species composition

and vegetation analysis of herbs, shrubs and trees life-form of plant present in study area. It also shows the biodiversity indices (Shannon-Winner Index, Simpsons' Index and Pielous' evenness) of plant life-forms. The quantitative vegetation analysis result is shown in the following parameters: density, frequency, dominance and important value index (IVI).and focuses on the plant species - environment relationships. Over a three-year period (2019–2022), the basic plant data was gathered and the soil nutrients from the soil sample were examined in a lab. Results using generalized linear model regression, Pearson correlation and ordination demonstrated the relationships. Forest wise species-depth wise environmental variables relationship were shown. Forest wise Clustering among the unique species, relation between biomass and elevation, relation between species richness and elevation and relation between species richness and biomass were presented in this chapter, biomass and carbon stocks, litter mass, fine roots and their carbon, and nutrients were presented and discussed. Also the plants found within the plots was categorized if it is within the IUCN category and within CITES. **Chapter 5** highlights the conclusion of the study and provides recommendation and management guidelines for this area. **Chapter 6** provides summary of the study.

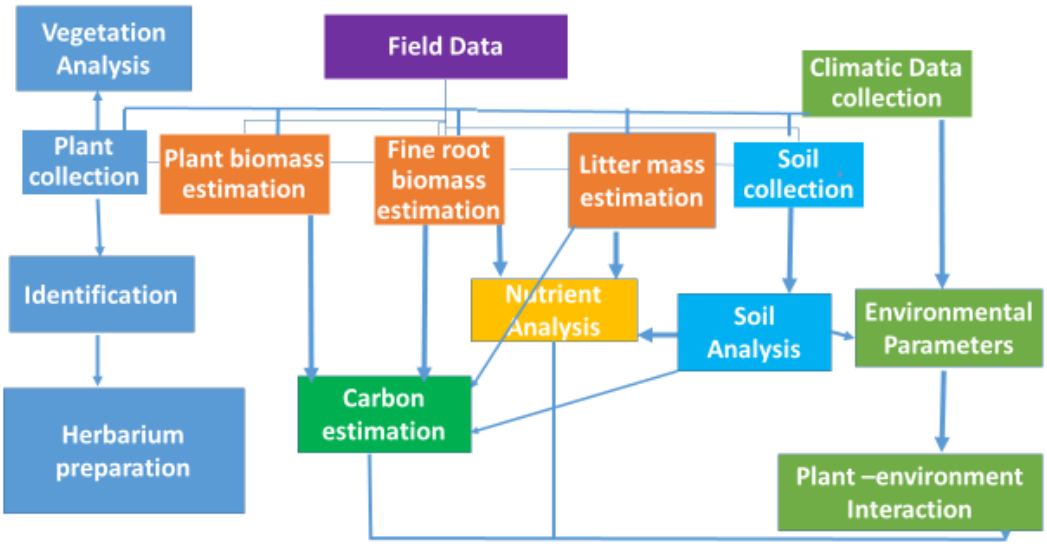


Figure 1: Conceptual framework of research work

CHAPTER 2

2.1 LITERATURE REVIEW

2.1.1 Species composition and diversity

Species diversity is a key factor in determining the productivity, stability, inevitability, and nutrient dynamics of ecosystems. The diversity and predictability of the environment in which a community develops determine species richness (Slobodkin & Sanders, 1969). It has been demonstrated that a range of ecosystems' species richness and diversity are significantly influenced by characteristics including soil nutrient content, slope, aspect, and elevation (Brocque & Buckney, 2003). Elevation itself is a complicated combination of associated meteorological factors that are strongly connected with a wide range of other environmental factors (Ramsay & Oxley, 1997).

Research on patterns of plant species richness along environmental gradients could be improved by using multivariate environmental gradients (Pausas *et al*., 2001). Comparative analysis of species abundance distributions based on species abundance models and associated diversity indices may be helpful for better understanding the diversity of a community (Aye *et al*., 2014).

The structure, species combination, and soil characteristics of a Tropical dry forest in Western India were investigated by Kumar *et al*. (2011) and Acharya *et al*. (2011). They found an average of 995 stems per hectare (>30 m DBH) in the forest stands. The mean tree species diversity indices for the plots were 5.57 for species richness index (S'), 1.08 for Shannon diversity index (H'), and 0.71 for equitability index. They revealed an important relationship between soil pH and stem density were found. The species diversity index had an important positive correlation with soil available P and a negative relationship with N, C, C: N, and C: P ratio.

The diversity of trees, shrubs, herbs, and climbers increases as the canopy opens up. This might be because the forest floor receives a lot of light, and the warm weather may be favorable to the regeneration of more tree, shrub, herb, and climber species. Contrary to this, herb and climber species richness was maximum on dry site whereas shrub species richness was maximum on moist site (Chandra *et al*., 2010).

The study carried out by Naidu & Kumar (2016) in tropical forests in Eastern Ghats of Andhra Pradesh, India, investigated that the three families with the highest importance value index were Combretaceae, Euphorbiaceae, and Anacardiaceae. With a tree density ranging from 435 ha^{-1} to 767 ha^{-1}, and an average basal area of 25.82 m^2 ha^{-1}, it was noted that Euphorbiaceae provided the most species. The Simpson index was between 0.96 and 0.97, the Shannon Weiner index (H') was between 3.76 and 3.96, the evenness index was between 0.60 and 0.78, and the species richness index was between 10.04 and 11.24.

The tree abundance, richness, and phylogenetic diversity first increased with increasing elevation, then reached maximum values at intermediate elevations, and finally decreased at the highest elevations. Tree species composition was mainly shaped by elevation ($p=0.001 < 0.005$), suggesting that intermediate elevations result in an environmental screening effect due to the abundance of energy and moisture resources (i.e., high temperature and humidity), which is typical of tropical forests (Zhu *et al*., 2019).

Number of woody species, their density and herbs species were maximum at 600–800 m moist evergreen deciduous forest of India, whereas, maximum number of shrub species in 800-1000 m forest were reported (Reddy *et al*., 2011).

The tropical wet evergreen forest had increase in the stand density, maturity index values, regular species distribution, and concentration of dominance in the west coast evergreen forest from low to high elevation, while declined in the vegetation's heterogeneous nature, species evenness, and diversity from low to high elevations due to the unfavorable edaphic and climatic environments (Varghese & Balasubramanyan, 1999).

Study of forest community structure is essential in order to manage the forest resources in a sustainable basis and so also the analyses of diversity of forest component. *Shorea robusta* was the dominant species of Banke national park in Banke district of western Nepal, followed by *Terminalia alata, Anogeissus latifolius, Mallotus philippinensis,* etc. on the basis of IVI (important value index) values. The park consists of a total density stand (D) of 291.48 trees per hectare and a basal area (BA) of 21.13 m^2 per hectare. *S. robusta* has the highest basal area (BA) and density (D) measurements at 46.07 trees per hectare and 5.07 m^2 per hectare, respectively.

The forest tree species had a species diversity index (H) of 1.32, species evenness (J) of 0.64, and a dominance index (C) of 0.08. The forest had strong regeneration capacity with a right-skew reverse J-shaped pattern (Napit, 2015).

The most crucial factor affecting species richness and composition is moisture. The species richness shows a plateau at elevations between 3000 and 4000masl. There is greater number of species in the northern aspect, than on the southern. The number of species rises from 3200 to 3400 m a.s.l., which was followed by a progressive decline up to 3800 m a.s.l. There is a considerable (r = 0.22) link between moisture and species richness above 3800 masl, where the number of species again increases toward high elevation (3900-4000 masl) (Panthi *et al*., 2007).

Woody life forms: trees, shrubs, and woody climbers show a strong correlation with climate, while, herbaceous life forms: herbs, grasses, and herbaceous climbers do not exhibit any statistically significant patterns between 100 and 1500 meters above sea level, subtropical to warm temperate climate in the south-eastern region of Nepal (Bhattarai & Vetaas, 2003).

On the tropical moist forest of the Sunsari district the value of tree species richness is lower in a disturbed forest, suggests that the pressure from anthropogenic disturbances is severe on the trees. Contrarily, forest disturbance encourages the diversity of herb and shrub species, which are able to withstand disturbances than trees. It might have something to do with the accessibility and utility of light in open areas and beneath canopies, or it might have something to do with the local population's disinterest in using herbs and shrubs as compared to trees (Gautam & Mandal, 2018). The Siwalik range in Nepal, often referred to as the Churia Hills, is made up of hills, steep land slopes, gorges, vast expanses of river, and temporary streams. Its entire size is 1,886,000 acres, or 13% of the country's total area. The three most prevalent species throughout the entire research region are *Shorea robusta, Terminalia alata, and Semecarpus anacardium* (Nirola & Jha, 2013).

Chure has diverse and dynamic forest ecosystems. The ecological imbalance in the Chure region is mostly caused by increased human activities, such as forest encroachment and deforestation. In Chure 14 different types of forest ecosystems, including seven new ones. *Hymenodictyon excelsum* Forest, *Syzygium cumini* Forest, *Terminalia anogeissiana* Forest, *Schima wallichii-Shorea robusta* Forest, *Pinus*

roxburghii Forest, and Bamboo thickets are the newly reported forest ecosystems, (Uprety *et al*., 2023).

Community forestry program is regarded as one of the most successful natural resource management programs in Nepal regarding restoring degraded land and habitats, conservation of biodiversity, raising supply of forest products, empowering women, marginalized groups, generating rural income and enhancing human resources (Acharya, 2007).

Community forests have increased biodiversity and general forest conditions. In comparison to government-managed forests and national parks. Community forestry has developed to be an essential component of rural livelihoods and the Nepali forestry sector. Without a doubt, by preventing the trend of deforestation and accelerating regeneration, community forests have set foundations for the conservation of biodiversity (Pokharel *et al.,* 2005). Pandey (2007) revealed that tree species diversity was higher in community-managed forest stands.

Maintaining compositional, structural and functional characteristics of forest ecosystem is one of the key strategy for conserving biodiversity (Franklin *et al.,* 2002).

Long-term forest resilience is maintained when biodiversity concerns are taken into account in community forestry strategies and initiatives. Incorporating biodiversity issues into community forestry in Nepal requires the implementation of such policies (Poudel *et al*., 2021).

2. 1. 2 Plant biomass and carbon stock

Forest is a rich carbon reservoir (Bazezew *et al*., 2015). Forest biomass gives opportunities for ecological visioning, sustainable forest management, improvement of ecosystem functioning and services and it also support in mitigating of climate change (Pan *et al*., 2013; Fayolle *et al*., 2016).

In forests, species, canopy cover, stand structure, and elevation frequently affect the carbon stock (CS) and biomass (Xu *et al*., 2020; Regmi *et al*., 2021). There is direct negative and significant effect of species richness on carbon sequestration. Forest density, variation in diameter at breast height (DBH) among trees, tree height classes, elevation, slope, and aspect, which have significant effects on carbon concentration

are responsible for the variations in carbon sequestration capacity across forest areas (Cherinet & Lemi, 2023).

Additionally, the separate effect of crown area, diameter at breast height, and height had a positive and significant effect on carbon sequestration. The 20% of variations on carbon sequestration are indirectly influenced by elevation (Ali *et al*., 2023). The carbon stocks of above- and below-ground tree biomass, as well as litter, are significantly influenced by elevation, whereas deadwood and soil organic carbon stocks are not influence. Lower elevations had higher levels of above- and below-ground biomass and litter carbon, which was a result of higher photosynthesis and net primary production and higher biomass production generally (Feyissa *et al*., 2013; Chimdessa, 2023).

From a global point of view, it is recognized that large diameter trees (diameter > 60 cm) contribute significantly to biomass regardless of their density and that their loss could result in a reduction in structural variation and the capacity of forests to absorb carbon (Lutz *et al*., 2021). Global atmospheric annual CO_2 concentration increases after long period of time (Friedlingstein *et al*., 2020; Kaushal & Baishya, 2021).

The primary forest has a far higher total aboveground carbon storage than the secondary forest. Although young trees in the size class at DBH 4.5 - 20 cm predominated both forests in terms of tree density, the size class at DBH > 20 - 40 cm in secondary forest and the size class at DBH > 60 - 80 cm in primary forest showed higher potential for sequestering carbon to (Piyaphongkul *et al*., 2011). Aboveground carbon stocks are larger than the belowground carbon stocks. Tree individuals with DBH > 70 cm produced the largest percentage of aboveground carbon (Daba *et al*., 2022). Degradation of forest is also responsible for loss of carbon. The loss of 206 kMg C (9 kMg C yr^{-1}) was attributed to deforestation, while emissions from degradation and the harvesting of wood are responsible for 1757 kMg C (80 kMg C yr^{-1}) and 221 kMg C (10 kMg C yr^{-1}, respectively) (Ahmad *et al*., 2018).

Schima wallichii has high capacity for storage of carbon stock, while there is only a moderate association found for diameter, there was a strong positive correlation for aboveground biomass when measured as diameter squared height (D^2H) (Tolangay & Moktan, 2022).

The biomass and carbon content in the Sal forest in dang district of Nepal are comparatively low than other studies in the Sal forest and other tropical forests due to the presence of small diameter height of tree in the forest (Regmi *et al*., 2021).

In the Plateau Sal forest environment of the Nepal Himalaya, as landslides aged, oven dried stand biomass increased, while net production increased up to 40 years and then decreased. In a mature forest site, the stand biomass was found to be 729 t ha^{-1}, and the overall production was 22.1 t $ha^{-1}yr^{-1}$ (Mandal, 1999).

Litter mass: Aboveground source of soil organic matter

The littermass, the litter on the forest floor is an important source of nutrient cycling which helps to improve the soil fertility in forest ecosystem. In an ecosystem, chemical and physical characteristics of litter have a significant impact on its mass-loss rates at a specific (Fogel & Cromack, 1977; Upadhyay & Singh, 1985).

The biogeochemical cycle and nutrients in ecosystems of forests are improved by plant litter. The principal source of soil organic carbon (SOC) is litter, and primary plant nutrient cycle production is often measured by litter production. Further Litter is an indicator of primary production in addition to tree heights and diameters (Vitousek, 1982).

Litter decomposition is an important ecosystem process and a key determinant of nutrient turnover and carbon cycling. Climate (actual evapotranspiration and average yearly temperature) is the main rate-regulating element. Precipitation affect litter decomposition. Early in the decomposition process, soluble substances and particularly soluble-rich litters vanished quickly. With continuous mass loss, nitrogen concentrations increased linearly, but ultimately decreased in foliage litters (McClaugherty *et al*., 1985). At high temperature and humidity, the mass loss and release of nitrogen and potassium were much higher in 6-12-month stage of decomposition than in the 0 to 6-month stage. After 6 months of disintegration, evergreen leaves considerably enriched phosphorus content. Compared to deciduous and evergreen leaves, herbs leave had much higher rates of mass loss and nutrient release. In the 0 to 6-month stage of decomposition, increasing precipitation from 400 to 800 mm accelerated mass loss and potassium release but low phosphorus release (Du *et al*., 2020). The annual mass loss ranged from 2.2% to 41.5% per year (Johansson *et al*., 1995). The relative influence of the litter quality, the soil

environment, and the enzyme activity on the losses of C and N changes as the litter decomposition process proceeds. While initial litter quality, subsequent litter quality, and the soil environment had an impact on leaf and root litter C loss (Su *et al*., 2022).

The amount of annual litter mass, seasonal variation and its turnover in Tarai Sal forest and Hill Sal forest of eastern Nepal accounted the total annual litter mass in Tatai Sal forest (6.73 Mg $ha^{-1)}$ was significantly ($p < 0.001$) higher than in Hill Sal forest (5.63Mg ha^{-1}). The seasonal pattern of litter mass was higher in summer in both the forest Tatai Sal forest (9.04 Mg ha^{-1}) and Hill Sal forest (7.44 Mg ha^{-1}). The turnover rate for litter mass on the forest floor was higher in Tatai Sal forest than Hill Sal forest. Standing state nutrient in the litter layer was higher in Tatai Sal forest than Hill Sal forest. These differences are due to differences in micro climate, soil properties and species composition (Bhattarai & Mandal, 2016).

In contrast to favoring secondary metabolite decomposition, leaf litter's persistent increase in inorganic nutrients actually slowed down the decay of the leaf litter. The strong favorable impact of leaf litter chemistry on soil microorganisms suggests that leaf litter plays a crucial role in improving nutrient cycling in *Z. planispinum* plantations (Song *et al*., 2023).

Fine root biomass: Belowground source of soil organic matter

The cycling of carbon and nitrogen in forests is greatly assisted by fine roots. Its characteristics are influenced by geographic variability, the seasons, and soil characteristics. Soil depth and seasons also responsible for the changes in fine roots. Fine root biomass and production was decreased significantly with increasing soil depth. Mostly upper layer of soil contains more fine roots than the lower soil depth. Between soil depths of 0-10 and 10-20 cm of forests, there are considerable differences in the bulk and production of fine roots. During the dry period, the mass of fine roots significantly decreases (Jiménez *et al*., 2009).

Annual fine root production was between 460.26 and 1583.55 kg ha^{-1} yr^{-1}, turnover rate ranging from 1.37 to 4.45 $yr^{-1.}$ The fine roots added carbon inputs of 154.38 to 564.20 Kg ha^{-1} yr^{-1} and nitrogen inputs of 6.58 to 24.34 Kg ha^{-1} yr^{-1} (Pandey *et al*., 2023). Phosphorus applications boost fine roots, and that sandier soils produced more fine roots than loam-based soils (Mosquera & Hurtado, 2022).

Fine roots are more likely to change their fine root biomass than their rooting pattern in response to changes in soil physicochemical parameters and stand age (Chang *et al*., 2012). Associations between stand fine root biomass and latitude, elevation and stand density are hardly significant. Trees have a greater correlation between fine root biomass and basal area, in comparison to stands. The association between tree fine root biomass and tree basal area was significantly linear. It is also significantly linearly related to leaf biomass (Zhou *et al*., 2018).

There are significant relationships between SOC, fine root biomass, and ecological factors (soil water content and soil bulk density). The increasing soil water content and conductivity aided the synthesis of SOC by enhancing root litter breakdown and fine root turnover. SOC levels rise in dry locations because increased bulk density and pH levels prevent SOC mineralization and soil biological activity (Tian *et al*., 2022). While, there are positive relationships with soil N and water content but a negative association with soil P. in fine root production greatly increases with ecosystem age (Uselman *et al*., 2007).

The dead fine root biomass in both stands exhibited high values in the summer (July or August), live fine root biomass often decreased in the late growing season (September-November) with a seasonal peak in the early growing season (April-June). While other nutrient concentrations show seasonal variations, nitrogen and phosphorus concentrations of live fine roots change little during the growing season (Kim, 2012).

Smaller fine roots with a diameter of less than 2 mm had biomass of 1.51 and 3.2 t ha^{-1}correspondingly in disturbed and undisturbed stands. In both the disturbed and undisturbed stands, the majority of the fine roots were found in the top 0–15 cm of soil (67% in the disturbed and 64% in the undisturbed). Compared to the disturbed stand (16.93 kg ha^{-1}), the undisturbed stand had a higher nitrogen stock in the fine roots (38.61 kg ha^{-1}) (Gautam & Mandal, 2013).

Elevation affects the concentration, stock, and uptake of nutrients in the fine roots of the Tarai Sal forest (TSF) and Hill Sal forest (HSF) in eastern Nepal. In comparison to Tarai Sal forest annual mean fine root biomass is greater in Hill Sal forest. Tarai Sal forest exhibits somewhat more nitrogen, phosphate, and potassium in its fine roots than Hill Sal forest. Whereas, the concentration of nutrients in fine roots with a

diameter of less than 2 mm is about 1.2 times greater than that in fine roots with a diameter of 2 - 5 mm in both forests, because of less net uptake and mineralization of carbon. Similarly, the Hill Sal forest showed a comparatively greater level of soil carbon stock (Bhattarai & Mandal, 2018; Bhattarai *et al*., 2020).

2. 1. 3 Soil characteristics

Soil physicochemical and hydrological characteristics varied with different land use systems in Nepal's tropical region (Shrestha & Kafle, 2020). The soil in forests is rich in terms of organic matter, nitrogen, and phosphorus but less fertile in terms of pH and potassium (Pandey *et al*., 2020). The higher organic matter levels in forest lands indicate to lower nitrogen-losing process activity (KC *et al*., 2013). Soil nutrients play an important role in the formation of plant communities, their species and structural diversity in all types of ecosystems. Soil conservation has fundamental significance for biodiversity conservation. High levels of atmospheric nitrogen (N) deposition are present in many tropical and subtropical regions in eastern Asia. Nutrient enrichment increases the biodiversity in poor soils (Theodose & Bowman, 1997). There is positive correlation between soil variables and tree diversity (Homeier *et al*., 2010).

Elevation plays a significant role in variation of climatic characteristics, soil properties and land use patterns (Deb *et al*., 2018). Soil nitrogen, organic matter, soil moisture, and water holding capacity increase with elevation, soil pH had a negative relationship with elevation. The soil of forest is acidic (pH 3.82-5.2). The pH is lowest in rainy season. Nitrogen content increases with elevation and shows highest during dry season. According to the study, N-rich soils at higher elevations are optimal for the growth and development of forests because they have favorable chemical characteristics that influence and are in turn affected by forest structure and composition (Malik & Haq, 2022).

Same was the case with Phosphorus as well. Potassium content is also higher in dry season and middle range (1900m-2300m) of elevation. Soil moisture is directly related to precipitation i.e. higher in rainy season and lower in dry season. Water holding capacity increases with elevation, whereas decreases during dry season (Sigdel *et al*., 2015).

Mostly soil carbon is in the form of organic carbon (C) which is obtained from the living organisms and has been stored in deeper soil layers below 20 cm over long

period of time (Fontaine *et al*., 2007). Generally speaking, 10% of the world's soil The growth of *Shorea robusta* (Sal) and other tree species, such as *Terminalia tomentosa* and *Syzygium cumini*in tropical forests are highly influenced by nitrogen (N), phosphorus (P), potassium (K), and soil pH (Seth & Bhatnagar, 1960; Bhatnagar, 1965). The ecology of litter and forest floor in forest eco- systems focused on their importance to soil health, nutrient cycling, and carbon balancing. To ascertain and comprehend the process and functioning of an ecosystem, it is crucial to assess the amount of forest floor and litter fall as well as its pattern of senescence in a specific site, habitat, and by forest types (Berg, 2000; Wang *et al*., 2008; Jhariya, 2017).

Water holding capacity (WHC) and Soil moisture (SM) showed similar results both increase with increase in elevation (Pattanaaik, 2014). The pH of the soil ranged from 5.5±0.20 to 6.6±0.26 clearly indicated that the soil is acidic in nature and there is not much variation in the pH values of different soil sample in all stands at different locations (Khan *et al*., 2010).

Nitrogen demonstrated a positive relationship with organic carbon while, water holding capacity shows a strong positive correlation with moisture content. On the other hand as elevation rise, the pH of the soil falls (Thakur & Bisht, 2020; Ren *et al*., 2022). The chemical properties affect and are reciprocally affected by forest structure and composition and that N rich soils of higher elevations are best for the growth and development of forests (Malik & Haq, 2022).

Pure *Shorea robusta* and mixed *Shorea robusta* forests' soils were examined for their physiochemical characteristics and reported sandy loam soil in both the pure and mixed forest and recorded 60.12% and 50.58% sand, 28.59% and 35.24% silt, and 11.12% and 22.41% clay, respectively. The pH level, as well as the amounts of phosphorus and water holding capacity, was lower in pure forest (4.33) than in mixed forest (5.26). Pure forests had the highest levels of humus, organic matter (Paudel & Sah, 2003). The Tarai *Shorea* forests had the highest levels of soil nutrients at all depths (Gautam & Chettri, 2020).

Soil P, K, and pH have no impact on the biomass of forests. As SOC, N, and bulk density respond inversely to biomass density, increased SOC does not necessarily result in higher biomass in the forest. Similarly, biomass density, N, and K have rarely an effect on SOC in forests (Pandey *et al*., 2020). The organic matter, total nitrogen,

organic carbon, and water holding capacity are all higher in the upper layer and decline with depth. The enhanced supply of nutrients from the degraded form of litter and the fine roots of the forest plants, as well as the decreased loss of top soil, are responsible for the higher level of soil nutrients in the upper layer (Gautam & Mandal, 2013). As the depth of the soil profile increases, the average total N, average P, and average K significantly decreases in *Shorea robusta* forest of Nepal. In forest soil, the depth of the soil profile significantly impacts the SOC stock and the soil's physicochemical characteristics (Lamichhane & Ghimire, 2022).

The study of Sapkota *et al*. (2017) in physicochemical characteristics of forest soils in Tarai and Siwalik regions of Nepal investigated that the Tarai and Siwalik areas of Nepal have different soil properties in terms of its physical and chemical components. The vegetation-covered parts of the land appear to be successful at preventing sheet erosion and, as a result, at keeping soils' crucial nutrients in place. Additionally, factors affecting soil quality include geographic location, the quantity of living things (including microorganisms), variations in relief, variations in watershed characteristics, and the stage of forest succession.

From the literature review, it has been known that forest is rich in species and diversity and are house of carbon. They are influenced by physico chemical characteristics of soil, soil depth and elevation. The diversity of herbs, shrubs and trees increases in open canopy as the forest floor receives required amount of light and warm weather favorable for regeneration of species. Litters and fine roots are the important source of organic matter. The turnover rate of litter mass on the forest floor is higher in Tarai Sal forest than the Hill Sal forest. However, limited researches have been conducted in plant species diversity of in relation to elevational gradient in this region of biodiversity hotspot and high biodiversity zone, i.e. lowland of eastern Nepal.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Study area

The study area is situated in the northern part of Morang district of Koshi Province in eastern Nepal and falls in the Tarai (plane area) and Siwaliks the lower Himalayan range within the Latitude: 26.20" to 26.53" and the Longitude: 87.16 to 87.51". The district is surrounded by Jhapa and Ilam district in the east, Sunsari district in the west, Dhankuta and Panchthar district in the north and boarder of Bihar province of India in the south. The area of Morang district is 1,855 square kilometers and its elevation ranges from 60 meters to 2,410 meters above mean sea level (m amsl). About 80% of the area in this district is in the Tarai region, with the remaining 20% belonging to the Chure hill and Mahabharata ranges.

3.1.1 Location

The five forest sites were selected between the elevation 100 m to 1300 m amsl in the Letang and Belbari Municipality of Morang district. The latitude and longitude of study area were ranged from 26°39'45.69"N to 26°48'28.68"N and 87°28'2.08"E to 87°28'45.06"E respectively. These five forests addressed here as Bhaunne (200 m), Raja-Rani (500 m), Murchungi (800 m), Adheri (1000 m) and Sagma (1200 m) forests (**Figure 1**). Among these five forests, Bhaunne forest lies in Tarai region in Belbari municipality, ward number 10 under Belbari-Chisang Community forest (1646.64. hectare area) While, Raja-Rani, Murchungi, Adheri and Sagma forest exist in Raja-Rani (299.5 (Block 4: 148.28 hectare), Akashe (146.05 hectare), Sat kanya (119.8 hectare), and Kuwapani Community forests (206.15 hectare) respectively in Letang Municipality ward number 1. The forests of the entire study area fall under tropical and lower subtropical region. Details of the five study sites are depicted in the **Table 1**.

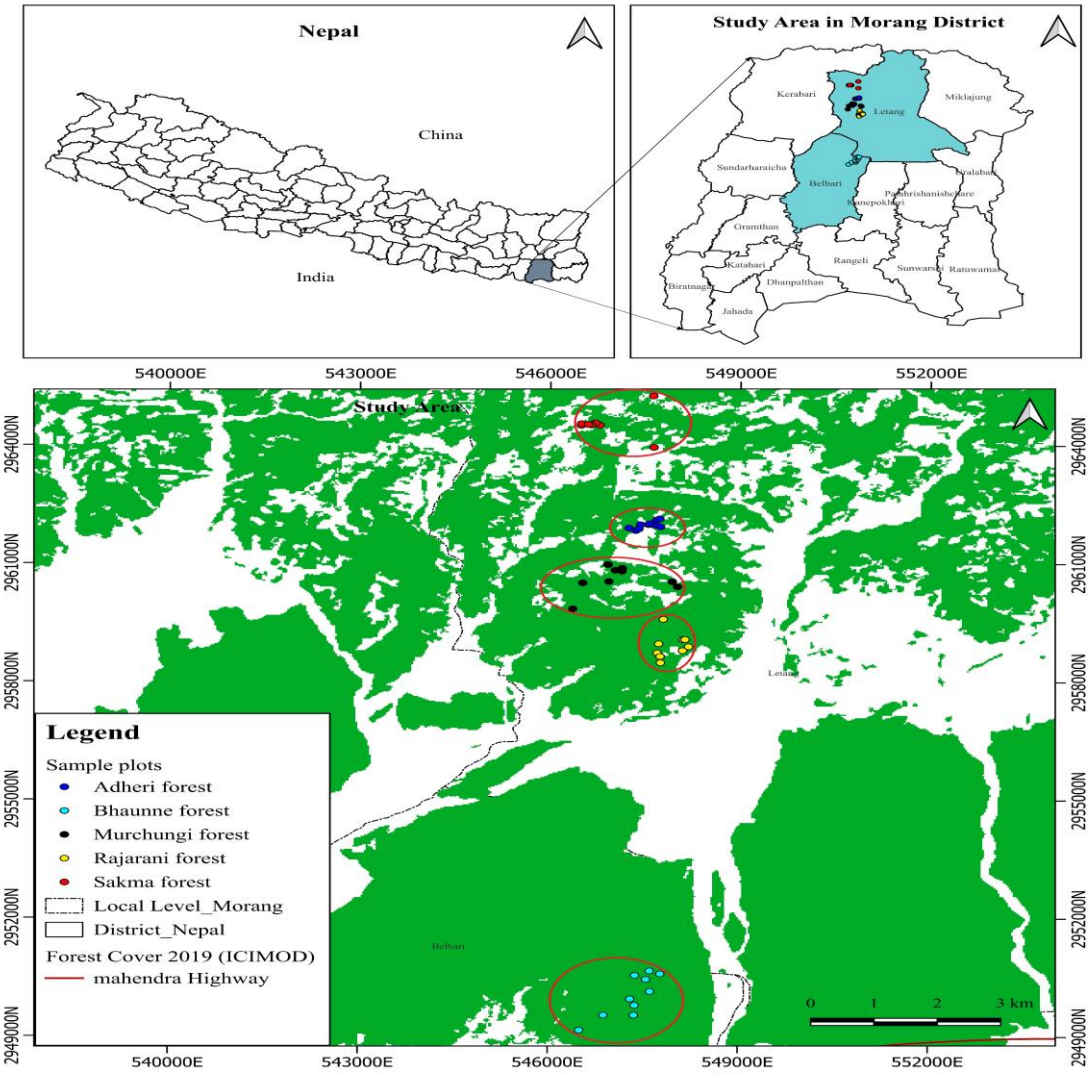


Figure 2: Map of the study area showing the layout and sampling plots.

The studied forest sites were located within the community forests. Though, as per the operational plan conducted by the community forest user groups, the dried and logged trees, branches are extracted from the forest yearly. Collection of litters and forest fires are not in existence. The present studied sites were allowed to protect and conserved all levels of the plant diversity with the coordination of community forest groups till the study period. So the studied sites were treated as protected and undisturbed forests. However, occasional grazing by cattle were seen in the forests. Therefore, it represents as if the natural forests with inconsiderable disturbance.

Table 1: Characteristics of forest sites

S.N	Forest Sites	Elevation Range(m asl)	Dominant Vegetation
1	Bhaunne forest	100-330	Dominated by *Shorea robusta* forest. The associated tree species are *Adina cordifolia, Alangium salviifolium, Casearia graveolens, Croton persimilis, Holoptelea integrifolia* etc
2	Raja-Rani forest	380-600	Raja-Rani forest is dominated by *Shorea robusta* with the association of *Schima wallichii* and *Croton persimilis*.
3	Murchungi forest	700-880	This forest also dominated by *Shorea robusta* forest. The associated trees are *Schima wallichii* and *Dalbergia stipulacea*
4	Adheri forest	900-1050	*Shorea robusta* is the dominant with *Schima wallichii* and *Casearia graveolens* as associated species in this forest.
5	Sagma forest	1100-1300	This is the upper most study site dominated by *Schima wallichii* with the association of *Engelhardia spicata, Castanopsis indica* and *Alnus nepalensis*.

3.1.2 Climate

The climate of this study area is characterized by tropical monsoon type. The study area has three distinct seasons: (i) dry and warm summer season (March to May); (ii) wet and warm rainy season (May to October); and (iii) dry and cool winter season (November to February). As per the nearest meteorological station, Dharan data of Bhaunne to Murchungi nearby study area averaged from 2000 to 2020, the mean annual minimum air temperature varied from 11°C to 25°C and the mean annual maximum air temperature varied from 21°C to 35°C and the average annual rainfall ranges from 2.8 mm to 551.2 mm in the studied forests region from Bhaunne to Murchungi, showing most of the time is moist (DHM, 2022) **(Figure 3)**.

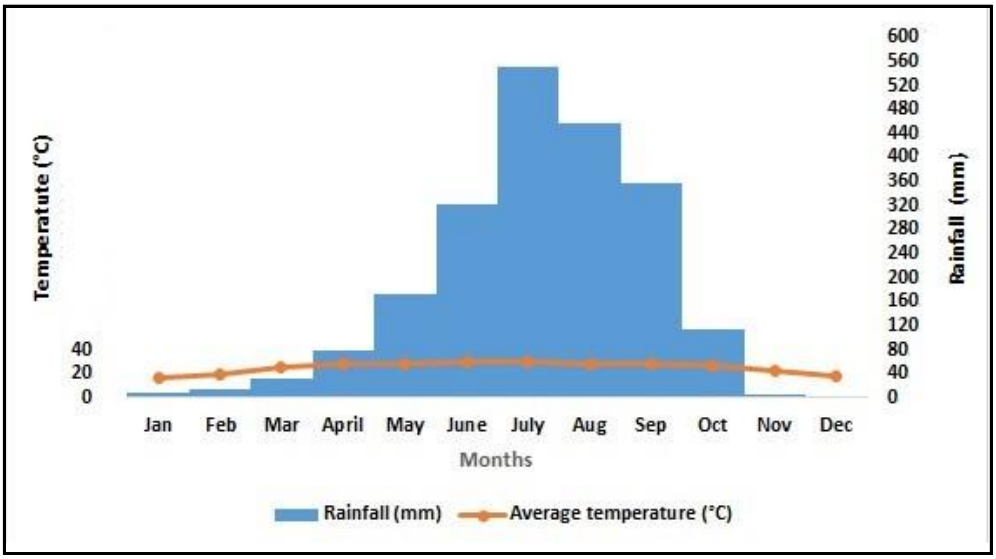


Figure 3: Ombrothermic graph showing relation between temperature and annual rainfall in the region of Bhaunne, Raja-Rani and Murchungi forests. Data pertain to the period 2000 to 2020 (Source: Department of Meteorology, Dharan, Nepal)

On the other hand, average minimum and maximum annual temperature in the region of Adheri and Sagma forests ranged from 7°C to 21°C, 20°C to 30°C respectively. The average annual rainfall ranged between 1 mm in November to 259 mm in July (**Figure 4**).

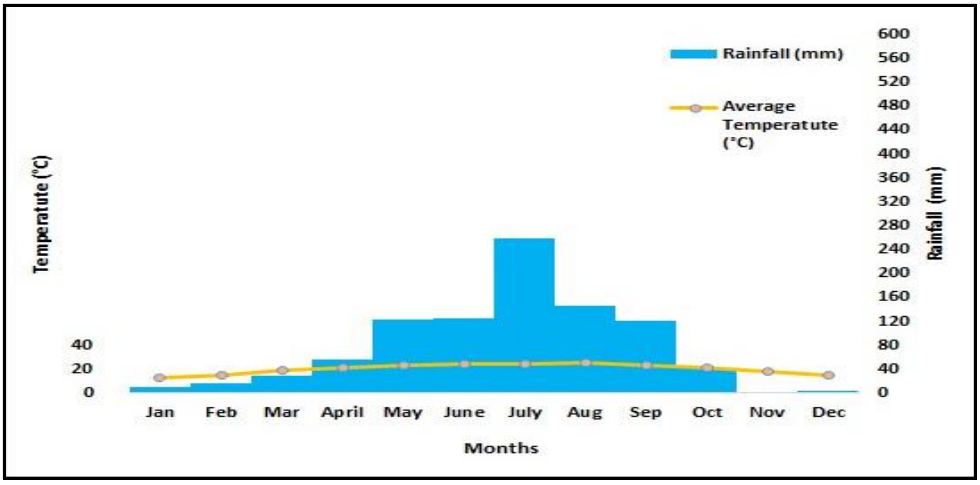


Figure 4: Ombrothermic graph showing relation between temperature and annual rainfall in the region of Adheri and Sagma forests. Data pertain to the period 2000 to 2020 (Source: Department of Meteorology, Dharan, Nepal).

Relative humidity is also higher in rainy season with highest value in July to September (89%) at Bhaunne, Raja-Rani and Murchungi forests (**Figure 5**). While Relative humidity at Adheri and Sagma forests area showed maximum value (86%) in

both July and September (**Figure 6**). Data of rainfall, temperature and humidity were provided by the Department of Meteorology, Eastern Regional Office, Dharan, Nepal.

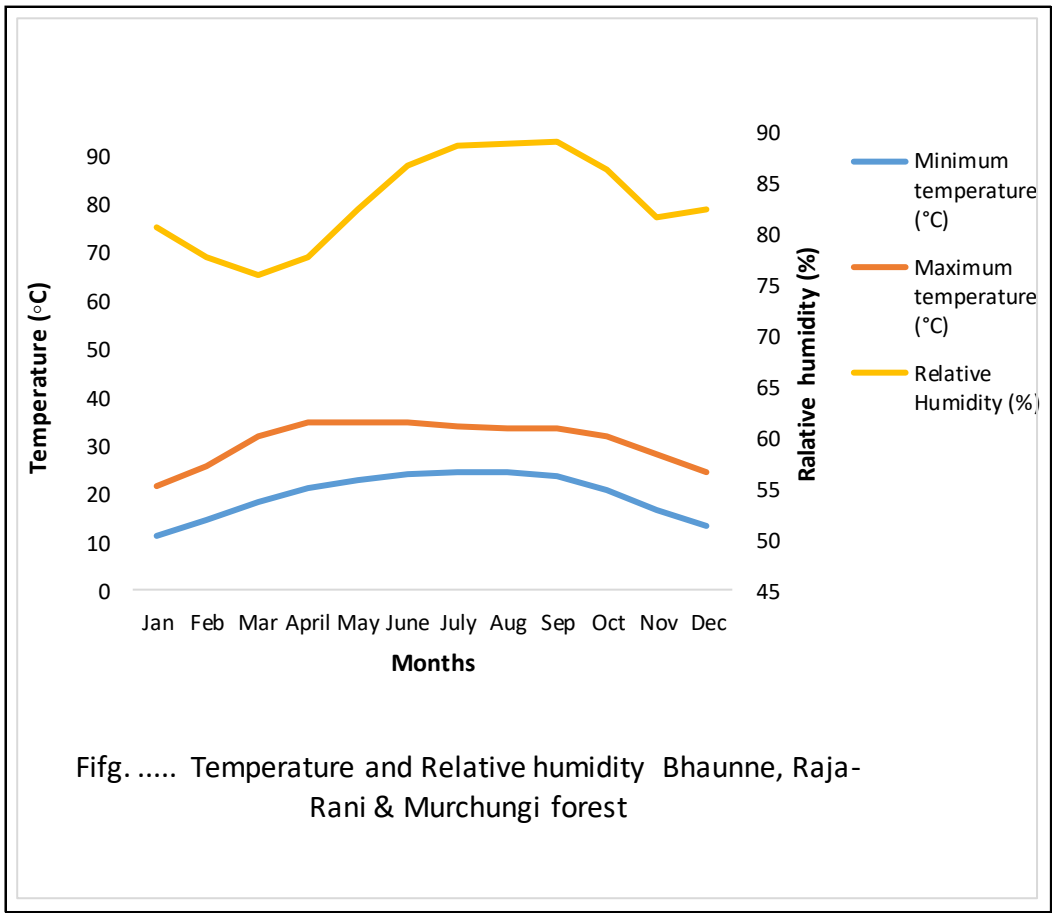


Figure 5: Temperature and relative humidity (%) of Bhaunne, Raja-Rani and Murchungi forests for the period 2000–2020 (Source: Department of Meteorology, Dharan, Nepal).

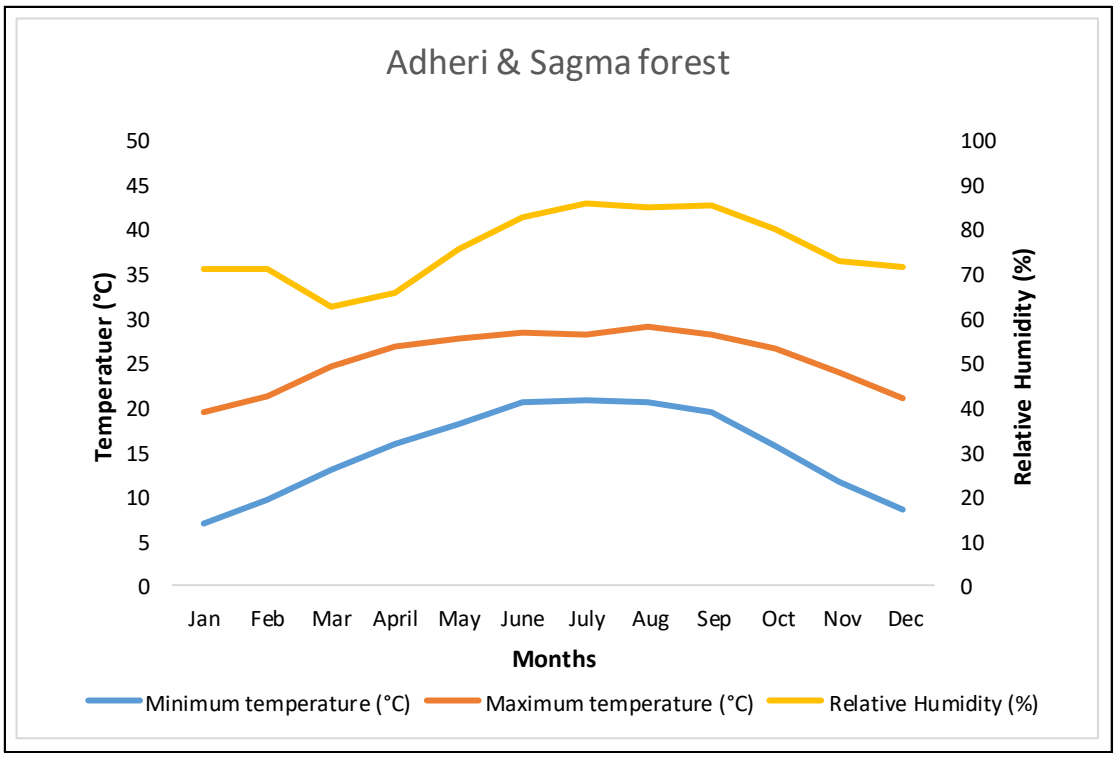


Figure 6: Humidity (%) of Adheri and Sagma forests for the period 2000–2020 (Source: Department of Meteorology, Dharan, Nepal).

3.1.3 Vegetation

The vegetation of the study area falls under the tropical moist forest as life zone classification method (Holdridge *et al*., 1971). The forests: Bhaunne, Raja-Rani, Murchungi and Adheri dominated by *Shorea robusta* Gaertn f. species. Other main associates were *Adina cordifolia* (Roxb.) Brandis, *Alangium salviifolium* (L.f.) Wangerin, *Casearia graveolens* Dalzell, *Croton persimilis* Mull.Arg., *Holoptelea integrifolia* (Roxb.) Planch. in Bhaunne, *Schima wallichii (*DC.) Korth, *Croton persimilis* Mull.Arg. species in Raja-Rani forest. *Schima wallichii (*DC.) Korth and *Dalbergia stipulacea* Roxb, in Murchungi and *Schima wallichii (*DC.) Korth, *Casearia graveolens* Dalzell in Adheri forest. While, Sagma forest was dominated by *Schima wallichii (*DC.) Korth and the main associates were *Engelhardia spicata* Lechen ex Blume, *Castanopsis indica* (Roxb. ex Lindl.) A.DC and *Alnus nepalensis* D. Don.

Dominant shrub species in Bhaunne forest was *Clerodrendrum infortunatum* L and main associate shrubs were *Leea indica* (Burm. f.) Merr., *Ardisia solanacea* Roxb. Likewise, the dominant herb species was *Oplismenus compositus* (L.) P. Beauv, main

associate were., *Pogostemon benghalensis* (Burm. f.) Kuntze and *Cynodon dactylon* (L.) Pers. On the other hand, Raja-Rani forest dominanted by *Maesa chisia* D. Don. shrub species and main associates herbs were *Leea macrophylla* Roxb. ex Hornem. and *Clerodrendrum infortunatum* L, Similarly, most dominant herb was *Koenigia mollis* (D. Don) T. M. Schust. & Reveal and associates were *Digitaria ciliaris* (Retz.) Koeler.and *Cyperus brevifolia* Rottb.Hassk.

Maesa chisia D. Don is the dominant shrub in Murchungi forest, while *Maesa macrophylla* (Wall.) A. DC.is the dominant shrub in Adheri and Sagma forests. In Murchungi, Adheri and Sagma forest second dominant shrub is *Ageratina adenophora* (Spreng.) R. M. King & H. Rob. *Imperata cylindrica* (L.) Raeusch.was the dominant herb in both Murchungi and Sagma forests, while *Elsholtzia blanda* (Benth.) Benth.was the dominant herb species in Adheri and main associate was *Imperata cylindrica* (L.) Raeusch.

3.1.4 Geology and Soil

The study area covers the plain region in the south and Siwalik Hills up to Mahabharata range in the north. The soil of study area is varied in character. In terms of texture, soils ranged from loamy sand to sandy loam varies along their depth and elevations. Sal forest has loamy soil and sand predominates in the soil. The sand content ranged between 51 to 83%, whereas the silt and clay contents are 13–37% and 3–13%, respectively. The soil chemical properties analyzed in the present work ranged between pH 5.06–5.73, organic carbon 0.95–3.04%, total nitrogen 0.09–0.26%, total phosphorus 11.01–302.7 Kg ha^{-1}, and potassium 16.90–397 Kg ha^{-1} (**Table 25 & 26**).

3.2. Data collection

3.2.1 Field work

The research permit to conduct this Ph.D. field work in the proposed area was taken. A reconnaissance visit to the research site was made, approximately six months before the fieldwork began. The study area was surveyed at first after talking to the local residents. The field work was carried out during 2019 to 2023. The field was visited during October- November, 2019, February-April, 2021, July-November, 2022

and on 2013 as per necessities for soil and vegetation data collection. Herbarium were collected during flowering season of plants.

Five forest stands; Bhaunne (200 m), Raja-Rani (500 m), Murchungi (800 m), Adheri (1000 m) and Sagma forest (1200) were selected as sampling sites, starting from lowland to highland in Morang districts of eastern Nepal. To cover the entire area of study sites and to cover maximum species, 50 sampling plots for each component: soil, vegetation, litter mass and fine roots, 10 samples of each component from each forest stand were laid randomly following Kershaw (1973) and Mishra (1968) (**Figure 7**).

3.2.2 Vegetation sampling and analysis

A total of 50 sampling plots, 10 plots from each forest, a plot of 20 m × 20 m size was laid down as a unit of a sampling plot for trees having ≥10 cm girth at breast height (1.37cm) above the ground. For shrubs, a nested sub-plot measuring 5 m × 5 m was laid down, while for herbs a nested sub-plot measuring 1 m x 1 m was selected in each forest stand (**Figure 7**). Plant species occurred inside each sampling plot was recorded, tagged and collected for herbarium preparation (Siwakoti & Rajbhandary, 2015).

Field note was prepared while collecting each plant. Global Positioning System (GPS) record, and other ecological information such as elevation, latitudes, and longitudes from the center of each plot were recorded. At least 2 specimens of each plant species were collected for herbarium which was prepared by following standard procedure.

In each plot for each forest stand, the girth of trees at breast height (1.37 m height) of each individual tree was measured and in case of shrubs at a height of 10 cm above the ground. Density, relative density, frequency, relative frequency, dominance, relative dominance was calculated by following Zobel *et al*. (1987). Basal area of individual tree species was determined for each species in each forest stand. Importance Value Index (IVI) of each species was calculated as sum of its relative density, relative frequency and relative dominance. Dominance was expressed in terms of biomass in herbs and as basal area in woody species. Inter-site comparisons

of vegetation composition were done through Sørensen's similarity index (ISs) as described by Mueller-Dombois & Ellenberg (1974):

$$ISs = 100 \times \frac{2C}{A+B}$$

Where, A = total number of species in site A

B = total number of species in site B

C = number of species common to two sites

Similarly, species diversity parameters such as Species richness (Margalef, 1958), Shannon-Wiener index (Shannon & Weaver, 1963) Evenness index (Pielou, 1969) and Concentration of dominance (Simpson, 1949) were determined from density values as below:

Species richness:

$$d = \frac{(S-1)}{\ln N}$$

Shannon- Wiener index

$$H' = -\sum pi \, Lnpi$$

Evenness index

$$e = \frac{H'}{\ln S}$$

Concentration of dominance

$$c = \sum (ni/N)2$$

where, S = total number of species in sample

N = total number of individuals of all species

pi = proportion of all individuals which belong to species i (ni/N)

ni = number of individuals of each species

H' = Shannon- Wiener index of species diversity

Information about rainfall, temperature, and humidity of the research area were provided by the Department of Meteorology, Dharan, Nepal.

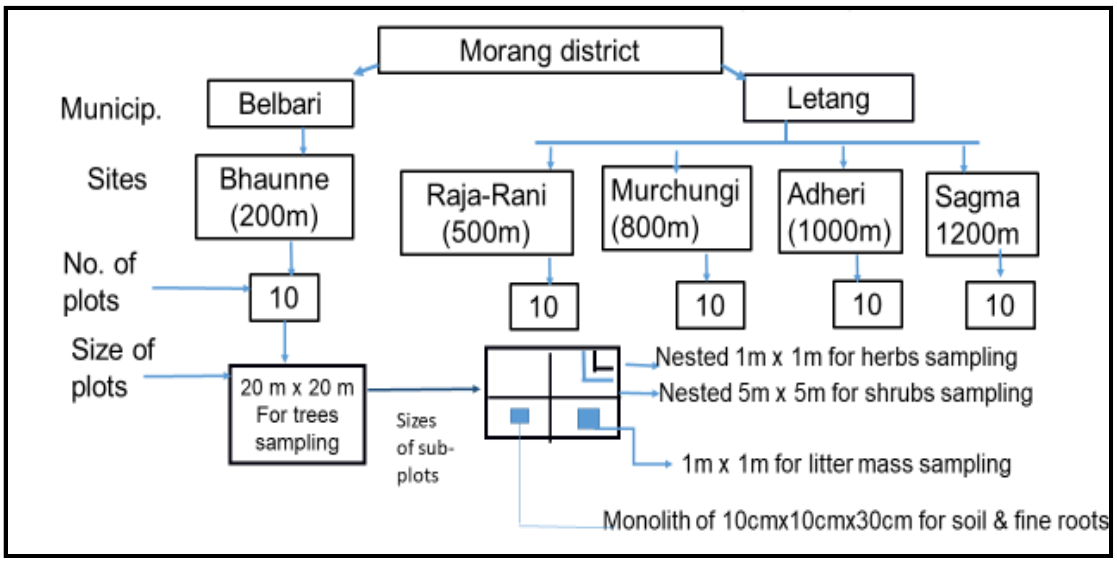


Figure 7: Sampling design and structure

3.2.3 Soil sampling and analysis

At each plot, the soil was collected from three pits sized 10cm x 10cm x 15 cm as upper (0-15 cm) depth and also in the same pit from 15-30 cm lower depth. For each depth, the soils of three pits were mixed and pooled as one replicate. Generally, the soil nutrients influenced by litter fall and fine roots are maximum in 0-15 cm depth and they decrease in 15-30 cm depth to the minimum level (Singh *et al*., 2001). So only these two depths have been considered in the experiment.

Physicochemical properties were determined for both upper and lower depth. Air dried soil samples were sieved through a 2 mm mesh screen and used for further analysis. Texture was determined by Sieve method, moisture, pH and water holding capacity (WHC) were determined following Piper (1966). Bulk density was determined by metallic tube method (Brady & Weil, 2013) and soil organic carbon by Chromic acid titration method (Walkley & Black, 1934). Total N was determined by micro-Kjeldhal method (Jackson, 1958) and total phosphorus by ammonium molybdate-stannous chloride blue color method (Jackson, 1958). Potassium was estimated by Flame photometer (Barnes *et al*., 1945). Carbon stock in soil was calculated by multiplying carbon concentration with bulk density of the soil for both

depths. Laboratory works have been done in the Ecology Research Laboratory of Degree Campus and also in Soil and Fertilizer Testing Laboratory, Jhumka, Sunsari.

3.2.4 Estimation of plant biomass and carbon stock

3.2.4.1 Estimation of plant biomass

Plant biomass was calculated for each forest stand within the designated sampling plots. Girth of tree species were measured at breast height (GBH) 1.37 m above the ground considering ≥ 10 cm GBH as trees (Dallmeier, 1992; Lalfakawma *et al*., 2009) and the girth of shrubs 10 cm above ground level were measured. The girth: biomass allometric equations (**Table 2**) for sub-montane Sal forest in Southern Siwaliks (available only for trees ≥30 cm girth) published by Singh & Singh (1992) were used to estimate the tree biomass in the plots.

The girth: biomass regression equations developed by Mandal (1999) for the Sal forest of the eastern Siwaliks of the Nepal Himalaya were used to estimate the biomass of Sal trees with girths 10-30 cm GBH and of shrubs also. The major root-biomass was estimated by using the root to shoot ratio developed by Singh (1974) for Sal forest. The aboveground herbaceous biomass was estimated by harvest method at all sites.

3.2.4.2 Estimation of litter mass

A sub plot of 1 m x 1 m was set up for the collection of litter mass within each of the 20m x 20m sampling plot used for vegetation sampling in each forest stand. Litter mass was collected during March-April of 2021. During this period generally the litter fall is at maximum level (Gautam & Mandal, 2016). The collection of litter mass was linked with maximum availability of litter fall. Selected forest sites were treated as undisturbed sites within the community forests. The litter collection practices and forest fire were not in existence in these forests. Litter mass that gathered at each site was collected and categorized as (a) fresh leaf litter; (b) non-leaf litter/ wood (which also included reproductive organs, such as flowers, fruits, and seeds). (c) Partially decomposed litter, decaying non-leaf litter (including highly fragmented dark material on the soil surface). Each categorized litter mass was oven dried at 80^0C for 24 hrs and then the content was estimated (Gautam & Mandal, 2016).

3.2.4.3 Estimation of fine root biomass

Fine roots (≤ 5 mm in diameter) were randomly collected from each plot. A soil monolith of 10 x 10 x 30 cm^3 that was separated into two depths upper (0–15cm) and lower (15–30 cm) at each location was used to collect the fine root. In order to remove any adhering materials, manually soil monoliths were washed with a water jet to retrieve the fine roots and oven dried at 80^0C. For the purpose of estimating biomass, fine roots were separated into two size group, smaller size 0-2 mm diameter and larger size 2-5 mm diameter (Gautam & Mandal, 2016).

Table 2: Allometric relationships between the biomass of tree and shrub components (Y, kg $tree^{-1}$) and circumference of Tree (X, cm at 1.37 m height) and shrub (X, cm at 10 cm height) respectively from the ground (Singh & Singh, 1992; Mandal, 1999).

	Biomass (kg $tree^{-1}$)	**Intercept (a)**	**Slope (b)**	**r^2**
Trees				
Shorea robusta				
	Bole	-2.832	1.976	0.980
	Branch	-2.037	1.501	0.992
	Twig	-2.688	1.463	0.980
	Leaf	-1.736	1.175	0.960
	Total	-1.789	1.892	0.980
Mallotus philippinensis				
	Bole	-2.1425	1.398	0.922
	Branch	-2.282	1.215	0.960
	Twig	-2.3285	0.810	0.922
	Leaf	-3.8605	1.066	0.902
	Total	-1.2385	1.281	0.960
Interspecies for *Shorea forest*				
	Bole	-5.0299	2.333	0.792
	Branch	-5.2096	2.081	0.828
	Twig	-4.6330	1.683	0.487
	Leaf	-4.9546	1.679	0.420
	Total	-4.3138	2.214	0.689
Shorea robusta (10–30 cm girth) class				
	Bole	-4.5149	2.2173	0.9498
	Branch	-6.993	2.3647	0.9649
	Twig	-8.0338	2.4048	0.9335
	Leaf	-4.0232	1.3612	0.9247
	Root	-4.2725	1.8340	0.9285
	Total	-3.5428	2.0742	0.9456
Shrubs				
Maesa chisia				
	Stem	-4.1008	1.6387	0.9405

	Leaf	-3.1204	0.8399	0.7758
	Root	-3.6681	1.2567	0.9735
	Total	-2.6115	1.3016	0.9560
Murraya koenigii				
	Stem	-3.5961	1.4555	0.9479
	Leaf	-3.2336	0.7828	0.7701
	Root	-3.2537	1.0923	0.9298
	Total	-2.3899	1.2146	0.9392
Shrub species pool				
	Stem	-7.1694	3.0945	0.9571
	Leaf	-4.6354	1.4607	0.6621
	Root	-6.9133	2.7756	0.9630
	Total	-5.4841	2.6518	0.9684

The equation is LnY = a + b Ln X; where Ln is natural log, 'a' intercept of 'Y' and 'b' is slope or regression coefficient. Equations for *Shorea robusta, Mallotus philippinensis* and Interspecies for *Shorea* forest are from Singh & Singh (1992); and for *Shorea robusta* (10–30 cm girth class) and shrubs are from Mandal (1999).

3.2.4.4 Estimation of carbon in vegetation, litter mass and fine roots

From each sampling plot, samples of various tree parts of the species were taken from the representative individuals of all available girth classes. From each site, samples of herbs (aboveground) and various parts of shrubs were gathered. Composite samples of trees, shrubs, and herbs were oven dried at 80 ^{o} C for 24 hrs. to a consistent weight. The leaf litter, wood litter, and partially degraded litter samples that had been oven dried were used separately for the further analysis. The fine roots of < 2 and 2–5 mm diameter size of all sampling plots were used separately and grounded for further chemical analysis.

The carbon concentrations were estimated by using the ash content method (McBrayer & Cromack, 1980), in which oven-dried plant parts such as stems, branches, roots, leaves, and litter (5g each) were separately burned at 400 °C in an electric Muffle furnace until the tissue turned to a grayish-white ash. The amount of ash (inorganic substances in the form of oxides) remaining after burning was measured, and carbon concentration was determined using the formula:

Carbon % = (Initial weight - Ash weight) x 100/2.

Carbon concentration (C %) were multiplied with dry mass to determine the carbon stock in vegetation. The conversion factors (carbon concentration) obtained in the present study for the conversion of different biomass components to carbon are shown in **Table 3**. The conversion factors as shown in **Table 4** were used for leaf and non-leaf and partially decomposed litter mass of five different forests. To obtain carbon stock in fine roots a conversion factor shown in **Table 5** was used for < 2 and 2-5 mm size class.

Table 3: Conversion factor of different components of trees and shrubs to convert biomass into carbon stock at different forest stands.

Forest stands		Components	Conversion factor	Forest stands		Components	Conversion factor
Bhaunne (200 m)	**Tree**	Leaf	0.39	**Murchungi**	**Tree**	Leaf	0.47
		Stem	0.4	**(800 m)**		Stem	0.47
		Root	0.47			Root	0.46
		Branch	0.44			Branch	0.47
		Twig	0.48			Twig	0.47
	Shrub	Leaf	0.44		**Shrub**	Leaf	0.48
		Stem	0.46			Stem	0.48
		Root	0.07			Root	0.45
	Herb		0.32		**Herb**		0.27
Raja-Rani	**Tree**	Leaf	0.46	**Adheri**	**Tree**	Leaf	0.42
(500 m)		Stem	0.45	**(1000 m)**		Stem	0.29
		Root	0.43			Root	0.42
		Branch	0.49			Branch	0.4
		Twig	0.44			Twig	0.42
Shrub		Leaf	0.46		**Shrub**	Leaf	0.45
		Stem	0.46			Stem	0.42
		Root	0.29			Root	0.39
Herb			0.32		**Herb**		0.43
				Sagma	**Tree**	Leaf	0.43
				(1200 m)		Stem	0.47
						Branch	0.48
						Twig	0.48
						Root	0.42
					Shrub	Leaf	0.47
						Stem	0.47
						Root	0.47
					Herb		0.42

Table 4: Conversion factor of different littermass components to convert into carbon stock

Components/ orests	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
Leaf	0.51	0.54	0.56	0.54	0.55
Non-leaf	0.41	0.22	0.54	0.55	0.55
Partially decomposed	0.30	0.25	0.30	0.43	0.34

Table 5: Conversion factor of fine root biomass to convert into carbon stock

Size class /Forests	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
<2mm	0.40	0.22	0.43	0.43	0.39
2-5mm	0.42	0.46	0.46	0.45	0.45

3.2.5 Plant identification

The collected plant specimens were identified using the standard literature (Hooker, 1872-1879; Hara *et al*., 1982, 1978; Hara & Williams, 1979; Grierson & Long, 1983, 1984, 1987, 1991, 1999, 2001; Obha *et al*., 2008; Polunin *et al*., 1987; Polunin & Stainton, 1984; Rajbhandari & Rai, 2017; Stainton & Polunin, 1988), Flora of Nepal, volume 3 (Eds. Watson *et al.*, 2013) and Catalogue of flowering plants of Nepal, vol. 1 (Rajbhandari & Baral, 2010), Vol. 2 & 3 (Rajbhandari *et al*., 2011, 2012) & and supplementary volume (Rajbhandari *et al*., 2015). Also unidentified plants were identified by consulting expert. All plant species and photographs were confirmed through comparison with specimens kept in the herbarium at the Post Graduate Campus, Biratnagar, Tribhuvan University, Nepal, and expert guidance. Kew's Powo.science.kew.org website published by The Royal Botanic Gardens was used to verify accepted and updated names of plant species.

3.2.6 Nomenclatures

The classification system used by Chase *et al*. (2016) for the Angiosperm Phylogeny Group-IV (APG-IV) system of classification were followed for the nomenclature of the plant species and their families included in this study.

3.2.7 Herbarium preparation

Voucher specimens were mounted in herbarium sheets following Siwakoti *et al*. (2015). All the voucher specimens prepared were deposited at the Tribhuvan University Central Herbarium (TUCH), Kirtipur, Kathmandu and Degree Campus Biratnagar, T.U.

3.3 Statistical analysis of data

The statistical analysis was done first after storing and entering all data into MS excel 2016 and then importing them into R and Rstudio (R Core Team, 2024). Before analyses, qualities of all responses in term of variance distribution, outliers and normality were tested. Normality of each response variable was checked through Shapiro-Wilks normality test (Shapiro & Wilk, 1965), boxplot, histogram and Q-Q plots (Karline *et al*., 2009. Quantitative relationship among variables were determined through Pearson's correlation. Pairwise comparisons of each life form richness and biomass responses against forests types and soil nutrients predictors were tested. 'Forests' was the fixed error and 'Plots' was the random error in this study. Thus, pairwise comparision (PWC) was done after partialling out or eliminating the random error caused by 'Plots' before applying pairwise comparison (PWC) (Dunn, 1964).

Species compositional patterns were determined through *vegan* (Oksanen *et al*., 2024) a multivariate analysis package. Elevational species richness patterns were analysed after using Generalized Linear Model (GLM, Hastie & Pregibon, 1992) up to first order.

3.3.1 Pearson's correlation

Pearson's correlation was applied among all soil variables at both the soil depths (0-15cm and 15-30 cm).

3.3.2 Friedman test

For the multiple comparisons of trees, shrubs and herbs biomass among five forest sites, first of all normality of biomass among three variables, trees, shrubs and herb were tested by using Shapiro test (Shapiro & Wilk, 1965).

To determine whether each measured response variable showed a statistically significant relationship among forests, each grouped under 10 random sampling plots,

one-way analysis of variance (ANOVA) was applied if normal assumptions were met by each response variable if not Kruskal-Wallis test or Friedman tests was utilized and then the Dunn's test (Dunn, 1964), which were pairwise comparison test for multiple groups was applied to identify which groups are significantly different from each other. The Dunn's test adjusts for multiple comparisons to control the familywise error rate. But before applying Dunn's test there must be statistical significant Kruskal-Wallis test. Bonferroni statistical method was used in the Dunn's test (Dunn, 1964),

Tukey Honestly Significant Differences (Tukey HSD) test was applied to determine which pair of forest variables were statistically significant if the distribution of error will be normal (Bunch, 2022). In case of non-parametric analysis, Dunn's test or Wilcoxon rank-sum test will be appropriate when response variable go maximum two levels. However, our main objective was to determine which pair of forests was significant. Thus, Friedman test was the appropriate choice of the non-parametric post hoc analysis. In the Friedman test the Bonferroni correction was applied to adjust multiple comparisons.

Visualizations of the Tukey's Honestly Significant Difference (Tukey HSD) post hoc test were done after plotting vertical bar plots. Similarly, non-parametric post hoc tests were displayed using boxplots or pairwise comparison graphs. Representation of the statistical significant or non-significant minimum percent change (MPC) was done through alphabets after standard deviation value of each measured variable. If two measured variables have two dissimilar alphabets ended after mean SD, these variables were statistically significant. If two same alphabets, then that will not be statistically significant.

3.3.3 Ordination

Ordination was done by utilizing the vegan package in R (Oksanen *et al*., 2024; R Core Team, 2024). The relation of species occurrence in ecological factors was done through multivariate analysis.

Redundancy analysis (RDA)

Prior to conduct redundancy analysis in this study, the Detrended correspondence analysis (DCA) (Hill & Gauch, 1980) technique was used to determine the strength of

sample by species data matrix from each forest stand's data independently. Detrended Correspondence Analysis (DCA) checks the homogeneity or heterogeneity of the all species, herbs, shrubs and trees dataset on the basis of axis length and Eigen value of DCA first axis. Since the Eigen value and axis length of the DCA first axis were less than 0.5 and 2.5 respectively, RDA was recommended. RDA is the linear direct gradient analysis.

3.3.4 Cluster analysis

To show the maximum similarity within a group and dissimilarity between groups, a *pvclustering* was used. Samples by species data matrix were grouped based on how abundant each species throughout sampling gradient. *pvclustering* is a probability value. The "*pvclust*" package (Suzuki & Shimodaira, 2006) in R (R Core Team, 2024) was utilized in order to obtain species cluster.

The *pvclust* is the multi scaled bootstrapping re-sampling method used by this program allows users to obtain uncertainty among clusters with *p*-values (Suzuki & Shimodaira, 2006). There are two types of p-values: essentially unbiased (AU) and bootstrap probability (BP) within each cluster or edge number that were calculated following a 1000-times multi-scale bootstrap re-sampling of the 50 samples that were given a standard error value. The ability to distinguish one cluster from another is made simple by using each edge or cluster number having its own unique p-value. Better or more significant clusters were those with higher (>=95%) AU and BP values.

Plant species occurred inside the plot of five forest sites were filtered into different degrees of overlapping prior to cluster analysis. Plant species that occurred only to a particular forest types were selected and the clustering was done after handling to such species only. So, the probability value clustering (*pvclust*) was fully relay on unique species of that particular forest only.

Thus drawn dendrogram represents species clusters. Each cluster shows how various species (indicated here by their abbreviations) are grouped based on their similarity (or dissimilarity). The height an axis represents the dissimilarity (or distance), with similar species being grouped together at lower heights. Three types of number each separated by different color: **Black (Above Branches)** are *Approximately Unbiased (AU) p*-values. They indicate the confidence in the clustering at each branch. Values

closer to 100% suggest higher confidence in the grouping of the species at that node. For example, at the branch grouping Tore.crus and Pier.ace, if the AU value is 100, meaning we can be confident that these two species belong in the same cluster. Likewise, numbers in **Red** are *Bootstrap Probability (bp) values*, which indicate the proportion of bootstrap replicates that contain the same cluster. Bootstrap values can sometimes be biased, so the AU *p*-value is often considered more reliable. Numbers in **Purple** are the edge numbers or cluster numbers, which simply help identify and refer to different branches in the dendrogram. Generally, red boxes are drawn in order to highlight clusters that are considered statistically significant based on the AU *p*-values (typically above 95%).

3.3.5 Multiple linear regression model for final best selection of variables

The main aim of this analysis was to determine the key environmental factors influencing the tree (Tsp), shrub (Ssp) and herb species richness (Hsp) among five spatially, and ecologically specified tropical to subtropical forest ecosystems of east Nepal. A dataset containing 63 various measured environmental variables was utilized to conduct the best model selection and analysis for these above mentioned predictor variables. The dataset was loaded into the R platform (R Core Team, 2024) for analysis. Missing values were handled appropriately. The Leaps Sequential Feature Selection ("*leapSeq*") method from the *caret* package (Kuhn, 2008) was employed for feature selection. Cross-validation was performed using the Repeated Cross-Validation (‘*repeatedcv*’) method with 10 folds repeated 3 times. A multiple linear regression model was fitted with the best-selected variables to predict the Tsp, Ssp and Hsp expression respectively.

The pattern of species richness along elevation was analyzed using a Generalized Linear Model (GLM) (McCullagh & Nelder, 1919) in R (R Core Team, 2024). Since the response variable represents count data, a Poisson family of regression was initially applied. However, over dispersion was detected in the data, prompting the use of the quasi-Poisson family of error distribution, which adjusts the standard errors to improve model fit. The generalized linear first-order model was tested against the null model, and the model's strength was evaluated using the deviance explained (r) value.

Deviance explained (r) refers to the proportion of deviance explained by the model compared to the null model (a model with only the intercept). It is analogous to R^2 in linear regression but is used in generalized linear models (*GLMs*), particularly when using non-Gaussian distributions like Poisson. A higher *r* indicates that the model explains a greater proportion of the variation in the data. It is also called as Pearson's Product-Moment-Correlation Coefficient.

r = 1- [Deviance of the Model/Deviance of the Null Model]

For the pattern of the relationship between biomass and elevation, a simple linear regression (McCullagh & Nelder, 2019) up to the first order was applied, as the response variable was continuous. The best-fitting regression line was determined using r, also known as the coefficient of determination or pseudo R^2. A higher *r* value indicates a better fit of the regression line. Both r and pseudo R^2 values range between 0 and 1.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Species composition and diversity

4.1.1 Characteristics of plant species

The total number of types of plant species found in five different forests was in the order of: Bhaunne > Sagma > Raja-Rani > Murchungi = Adheri. Combining all types of species of all growth forms e.g. herbs, shrubs and trees maximum number of plant species were found in Bhaunne forest (142 species), while minimum number of species were in Murchungi and Adheri forest (121 species in each) (**Table 7**). Species accumulation curve showed there were adequacy of sampling and number of species occurred in the study area (**Figure 8**).

Altogether 82 families of the plants were recorded in this study. Herb and shrub species both contained to 35 families each, whereas tree species consisted under 48 families. Maximum number of families i.e.55 were encountered in Raja-Rani forest and the lowest i.e 50 families in both Murchungi and Sagma forest (**Table 7**). Top 20 families covered 69% species out of 315 species and 66% genera out of 250 genera (**Table 6 & 8**). The family Asteraceae contained highest number of species and genera as, 31 and 28 respectively followed by family Fabaceae, Lamiaceae, Poaceae and so on. Altogether 21 plant species were of different growth forms common in all the five forests, such as *Acer oblongum* Wall. ex DC., *Achyranthes aspera* L, *Chromolaena odorata* (L.) R. M. King & H. Rob., *Lantana camara* L., *Maesa chisia* D. Don. And so on (**Figure 9 and Table 9**). Presence of same species in five forests may be due similarity in structure and their position on the landscape, and similar geography and climatic conditions. Occurance of *Chromolaena odorata* in all forest could be because of its light weight seeds which easily dispersed by wind, a character which makes Asteraceae a most successful family (Pandey & Singh, 1985).

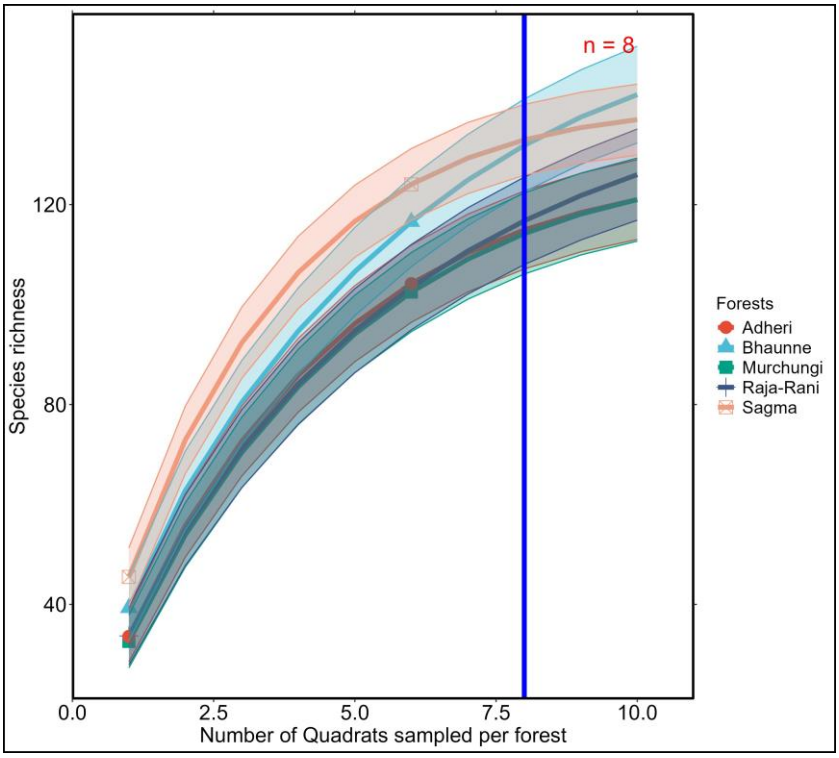


Figure 8: Species accumulation curve representing the adequate species richness

Herb layer

A total of 143 herb species were encountered across the five studied forests (**Table 6**). The number of herb species present in each forest was in the following order of Bhaunne forest> Sagma forest > Raja-Rani forest > Adheri forest > Murchungi forest. The largest number of herbs species (62 spp.) was enumerated from Bhaunne forest and lowest number of species were enumerated (45 spp.) in Murchungi forest. Total species content gradually decreased up to Murchungi forest and then again increased at Sagma forest (**Table 7**). The density of herb species ranged between 18 and 44.1 indi. m^{-2} along five different forests, minimum density was in Raja-Rani forest and maximum density was in Sagma forest (**Table 8**), which are comparable with the values (27.3-42.65) reported by Devi & Yadava (2006) and higher than the values (0.05-2.4) reported by Lalfakawma *et al*. (2009).

Table 6: Total number of species, genera and family combining five forests located at different e**levations.**

Growth form	Total	Herb	Shrub	Tree
Species number	315	143	69	103
Genera	250	112	62	87
Family	**82**	**35**	**35**	**48**

Table 7: Characteristics of plant species of forests located at different elevations in Morang district, e**astern Nepal.**

Parameters	**Forest stands**				
Forests	**Bhaunne**	**Raja-Rani**	**Murchungi**	**Adheri**	**Sagma**
Elevation (m asl)	**200**	**500**	**800**	**1000**	**1200**
Number of species					
Herbs	62	50	45	47	58
Shrubs	21	25	28	31	40
Trees	59	51	48	43	39
Total Species	**142**	**126**	**121**	**121**	**137**
Number of families					
Herbs	23	21	18	22	20
Shrubs	15	16	16	18	26
Trees	31	31	30	29	22
Total families	54	55	50	52	50
Number of genera					
Herbs	57	40	40	43	51
Shrubs	20	23	25	28	37
Trees	50	45	44	40	35
Total genera	127	108	109	111	123

Table 8: Density and Basal area of growth forms of forests located at different elevations in Morang district e**astern Nepal.**

Parameters	**Forest stands**				
Forests	**Bhaunne**	**Raja-Rani**	**Murchungi**	**Adheri**	**Sagma**
Elevation (m asl)	**200**	**500**	**800**	**1000**	**1200**
Density					
Herbs (ind.m^{-2})	23.6	18	19.5	20.5	44.1
Shrubs (ind. ha^{-1})	14000	11720	14240	11320	24400
Trees (ind.ha^{-1})	935	950	775	985	602.5
Basal area of shrubs (m^2 ha^{-1})	3.65	5.78	5.50	6.06	11.15
Basal area of Trees (m^2 ha^{-1})	54.30	43.98	61.20	50.10	34.35

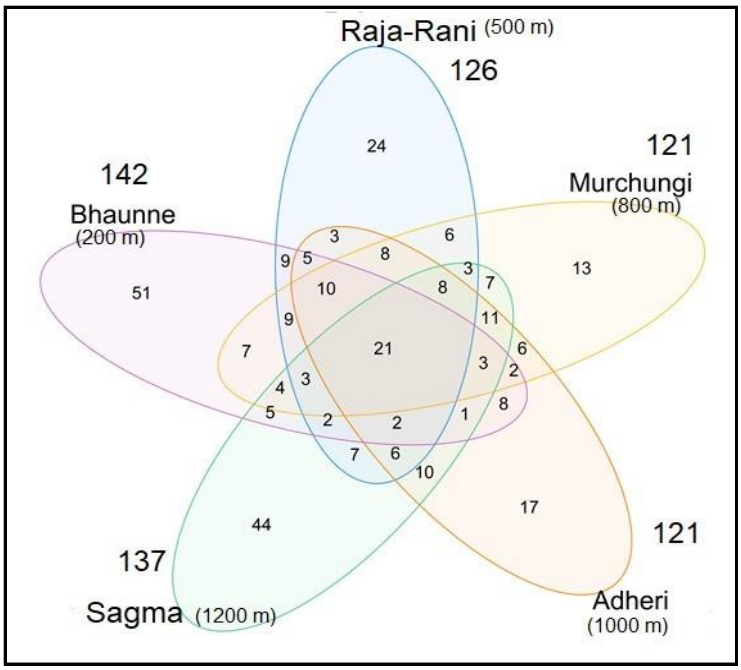


Figure 9: Venn-Diagram showing community composition variation among forest types.

Numbers without parenthesis represent the number of species or taxa occurred in that particular forest. Number in the parenthesis represents elevation of that particular forest. Numbers occurred in the shared forest represent that taxa occurred and shared with other type of forest as well.

Table 9: Top Twenty families on the basis of number of species content

S.N.	Family	Individuals	No.of species	No. of genera
1	Asteraceae	744	31	28
2	Fabaceae	250	27	21
3	Lamiaceae	638	24	17
4	Poaceae	370	19	15
5	Acanthaceae	149	13	9
6	Rubiaceae	96	13	12
7	Malvaceae	65	11	9
8	Urticaceae.	49	9	8
9	Euphorbiaceae	173	8	7
10	Rutaceae	64	7	7
11	Cyperaceae	78	7	2
12	Commelinaceae	65	7	5
13	Apocynaceae	64	6	6
14	Phyllanthaceae	28	6	3
15	Moraceae	26	6	2

16	Combretaceae	27	5	2
17	Lauraceae	67	5	4
18	Zingiberaceae	26	5	3
19	Anacardiaceae	37	4	4
20	Meliaceae	26	4	4

Table 10: Common plant species of different growth forms found in all the five studied s**orests**

S. No.	Scientific Name	Habit	Family
1	*Acer oblongum* Wall. ex DC.	T	Sapindaceae
2	*Achyranthes aspera* L.	H	Amaranthaceae
3	*Ageratina adenophora* (Spreng.) R. M. King & H. Rob.	S	Asteraceae
4	*Ageratum conyzoides* L.	H	Asteraceae
5	*Chromolaena odorata* (L.) R. M. King & H. Rob.	S	Asteraceae
6	*Clerodrendrum infortunatum L*.	S	Lamiaceae
7	*Clerodendrum japonicum (*Thunb.) Sweet	S	Lamiaceae
8	*Colebrookea oppositifolia* Sm.	S	Lamiaceae
9	*Curculigo orchioides* Gaertn.	H	Hypoxidaceae
10	*Cynodon dactylon* (L.) Pers.	H	Poaceae
11	*Digitaria ciliaris* (Retz.) Koeler	H	Poaceae
12	*Drymaria diandra* Blume	H	Caryophyllaceae
13	*Elaeagnus infundibularis* Momiy.	S	Elaeagnaceae
14	*Imperata cylindrica* (L.) Raeusch.	H	Poaceae
15	*Justicia adhatoda* L.	S	Acanthaceae
16	*Lantana camara* L.	S	Verbenaceae
17	*Maesa chisia* D. Don.	S	Primulaceae
18	*Mallotus philippensis* (Lam.) Müll.Arg.	T	Euphorbiaceae
19	*Mikania micrantha* Kunth	H	Asteraceae
20	*Oplismenus compositus* (L.) P.Beauv.	H	Poaceae
21	*Syzygium cumini* (L.) Skeels	T	Myrtaceae

Where, H-herb, S-Shrub, T-Trees

The most dominant herbs were *Oplismenus composites, Koenigia molis,* and *Esholtzia blanda* in Bhaunne, Raja-Rani, and Adheri forest respectively. *Imperata cylindrica* was most dominant species in both Murchungi and Sagma forest. Top ten herb species contributed 39 % of the total IVI out of 62 species present in Bhaunne forest. In Raja-Rani forest, ten herb species shared 43% of the total IVI out of 50 species. Similarly, ten herb species in Murchungi forest contributed 38% of the total IVI out of 45

species. Furthermore, ten most dominant herb species shared 54% of the total IVI out of 47 species in Adheri forest and ten dominant herb species in Sagma forest, consisted 40% of the total IVI out of 58 species (**Figure 10**).

Indices of similarity showed a maximum similarity i.e.46 % of species composition were similar between Raja-Rani and Murchungi forest. The minimum similarity (28%) was found in in the herb species composition between Bhaunne and Sagma forest (**Table 11**). In contrast to present study, *Oplismenus composites* was recorded as second dominant species in low land moist tropical forest by (Gautam & Mandal, 2018).

Table 11: Sørensen's Similarity Index (%) of herb species among five f**orests**

	Bhaunne (200 m)	Raja-Rani (500 m)	Murchung (800 m)i	Adheri (1000 m)	Sagma (1200 m)
Bhaunne	100	34	38	31	28
Raja-Rani		100	46	41	43
Murchungi			100	41	41
Adheri				100	40
Sagma					100

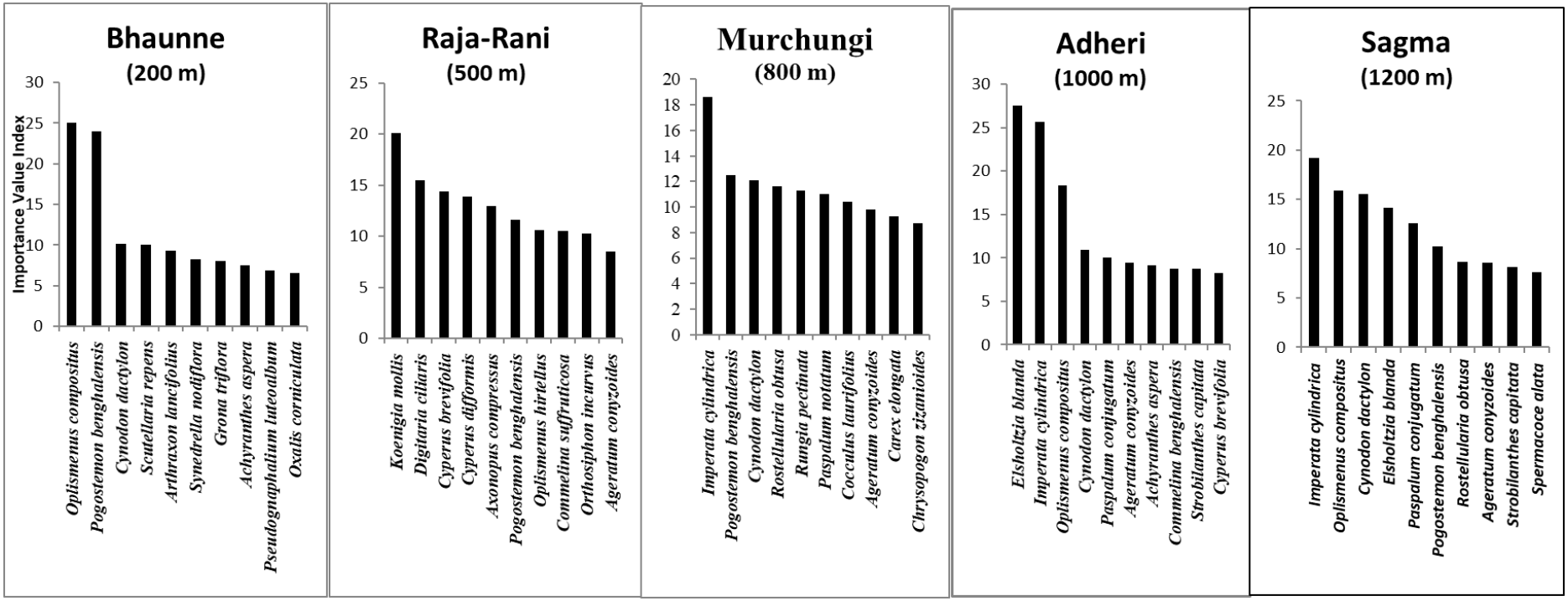


Figure 10: Ten dominant herb species on the basis of IVI in five different forests located at different elevations in Morang district, eastern Nepal

Shrub layer

Altogether, 69 species of shrub were recorded across the five forests. Among them maximum number of species (40 spp.) were in Sagma forest and minimum number of species (21spp.) were in Bhaunne forest. The shrub species exhibited increasing trend in the forest along increasing elevation in the order of: Sagma forest > Adheri forest > Murchungi forest > Raja-Rani forest > Bhaunne forest (**Table 7**). Higher number of shrub species in high elevation forests may be due to an open canopy and edge effect that favors light-loving plants. Alternatively, the dense tree canopy that tends to block the undergrowth from receiving enough sunlight for germination, growth, and development in light-loving species may be the reason for the lesser number of species seen in Bhaunne forest (200 m). Likewise, Reddy *et al.* (2011) revealed maximum number of shrub species in 800-1000 m elevation. The most dominant shrub speices recorded in Bhaunne forest was *Clerodendron infortunatum* with 56.43 IVI value, while *Maesa chisia* was dominant in Raja-Rani and Murchungi forest. *Maesa microphylaa* was dominant in Adheri and Sagma forest.

Contribution in total IVI by top ten shrub species in each forest were 45% out of 21 species in Bhaunne forest, 44 % out of 25 species in Raja-Rani forest, 42 % out of 28 species at Murchungi forest, 42 % out of 31 species in Adheri forest and 39 % out of the 40 species in Sagma forest (**Figure 11**).

Comparing all five forest sites, high similarity of shrub species composition i.e 75% was found between Murchungi and Adheri forest among the forests and lowest similaririty (36 %) in species composition was accounted between Bhaunne and Adheri forest (**Table 12**). In the coherence of present study, *Clerodendrum infortunatum* was found as dominant species in low elevation tropical forest (Gautam & Mandal, 2018).

Density of shrub species ranged between 11320 indi. $ha^{-1}$and 24400 indi. ha^{-1}among the five different forests. Minimum densisity was in Adheri forest and maximum density was in Sagma forest. Basal area ranged from 3.65 m^2ha^{-1} at Bhaunne forest to 11.15 m^2ha^{-1} at Sagma forest. Maximum values in Sagma forest may be due to higher density of shrubs (**Table 8**). Density value of shrubs density of the present study was compared with results of some tropical forest species of Nepal and India and found three cases; In some cases, it was lower, in some cases higher and comparable also.

Density values are higher than the values, 1786-5457, 4267-5222, 1845 and 4138-4708 reported by Shrestha (1997), Marasini (2003), Sukumaran *et al.* (2018) and Acharya & Shresth (2011) respectively.

Table 12: Sørensen's Similarity Index (%) of shrub species among five f**orests**

	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
Bhaunne	100	48	41	36	39
Raja-Rani		100	57	50	43
Murchungi			100	75	50
Adheri				100	62
Sagma					100

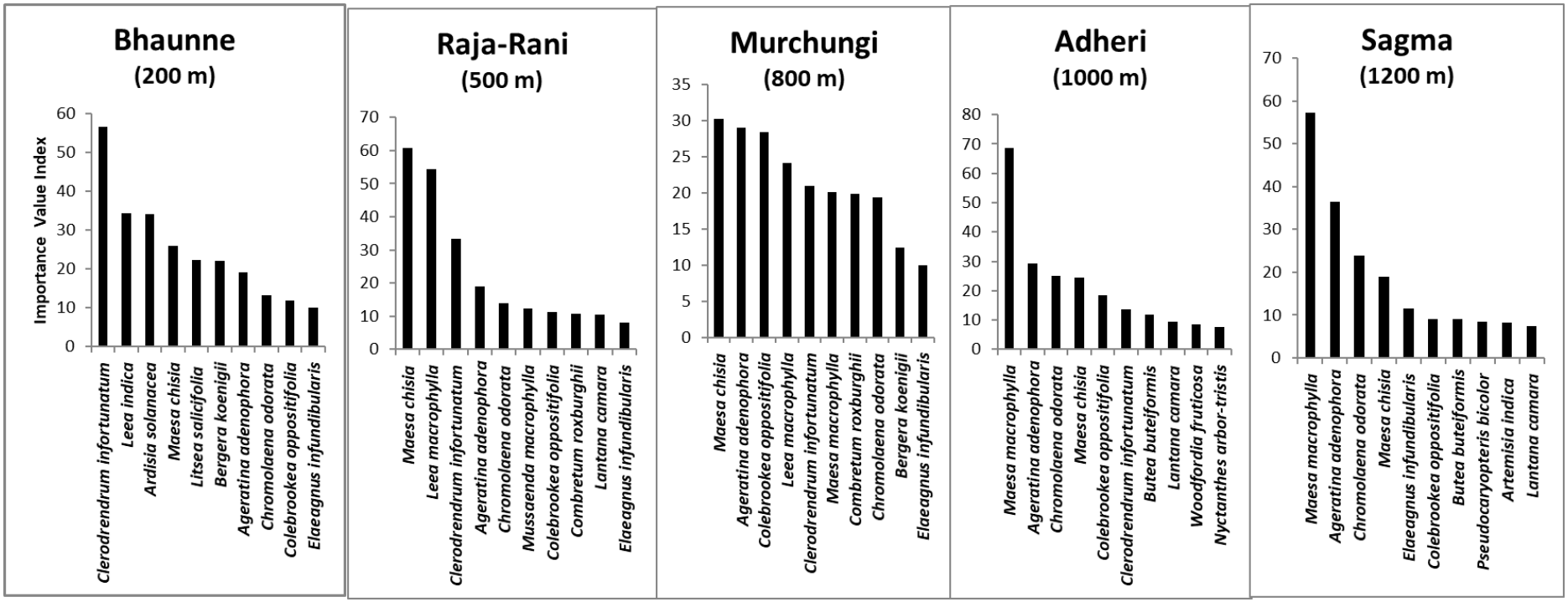


Figure 11: Ten dominant shrub species on the basis of IVI in five different forests located at different elevations in eastern Nepal.

Tree layer

Species content

Altogether 103 tree species were recorded along the five different forests (**Table 6**). Among them, the maximum number of species (59 spp.) was recorded in Bhaunne forest and the minimum number of species (39 spp.) was in Sagma forest. It showed gradual decreasing trend in tree species from the forest at low elevation to the forest at high elevation forest (**Table 7**).

The tree species, *Acer oblongum*, *Mallotus philippensis* and *Syzygium cumini* were common to all the five forests. The number of tree species restricted to Bhaunne forest only was 16, whereas 6 species confined to only at Raja-Rani forest. Similarly, 3 tree species: *Diospyros montana*, *Senegalia intsia*, and *Terminalia myriocarpa* were found only in Murchungi forest. While *Elaeodendron glaucum*, *Ligustrum robustum*, and *Pouzolzia rugulosa* were observed only at Adheri forest. On the other hand, 11 different tree species were confined in Sagma forest only (**Table 10**, **Figure 9** and **Appendix I**).

The number of tree species is low in Sagma forest than the Bhaunne forest. The higher species richness in Bhaunne forest may be due to higher soil moisture and nutrients. On the other hand, less number of species in Sagma is attributed to environmental factor (climatic factor). Tree species richness of present study forest is quite higher than the matured Plateau Sal forest of eastern Siwaliks, Nepal (Mandal, 1999), Higher species richness in the present forest as compared to dry forests might be due to higher value of annual precipitation.

Maximum similarity in species composition, 64 % was found between Murchungi and Adheri forest, while minimum similarity of species composition, 22 % was found between Bhaunne and Sagma forest (**Table 13**). Similarity of tree species may be due to similar environmental condition and geography (Bhatnagar, 1965).

Table 13: Sørensen's Similarity Index (%) of tree species among five f**orests**

	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
Bhaunne	100	56	52	55	22
Raja-Rani		100	63	62	33
Murchungi			100	64	51
Adheri				100	46
Sagma					100

Importance Value Index (IVI) of tree species

Based on the IVI, Bhaunne forest exhibited dominance of *Shorea robusta* (37.23), followed by *Adina cordifolia* (21.18) and so on. In the same way, *Shorea robusta* (81.81) was the most dominance species followed by *Schima wallichii* and *Croton persimilis* and so on in Raja-Rani forest. While *Shorea robusta* (116.40) followed by *Schima wallichii* (16.30) in Murchungi forest. Likewise, *Shorea robusta* (134.78) was dominant followed *Schima wallichii* (19.81) in Adheri forest. Further, *Schima wallichii* (69.08) was the most dominant species followed by *Engelhardia spicata* (44.25) and *Castanopsis indica* (24.23) in Sagma forest. Here *Shorea robusta* was abundant in four forests of tropical region. Napit (2015) also found *Shorea robusta* as the dominant species in Banke National Park, Nepal. Whereas, *Shorea robusta Terminalia alata*, and *Semecarpus anacardium* are the prevalent species recorded by Niroula & Jha (2013) in tropical forest. Contribution in total IVI by top ten species in Bhaunne forest were 49.22 % out of 59 species, 69 % out of 51 species in Raja-Rani, 65 % out of 48 species in Murchungi, 68 % out of 43 species in Adheri, and 66 % out of 39 species in Sagma forest (**Figure 12**).

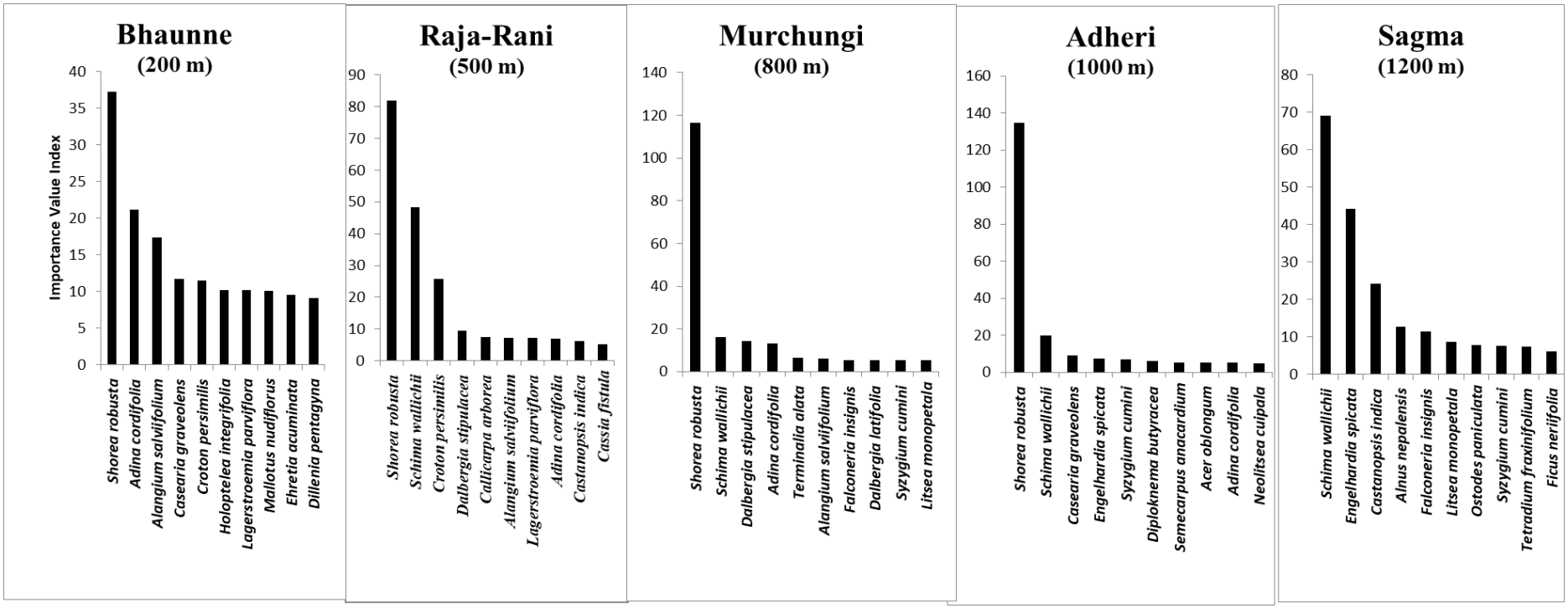


Figure 12: Ten most dominant tree species of five different forests on the basis of IVI

Stand density of tree species

The total stand density of trees ranged between 602.5 indi. ha^{-1} and 985 indi. ha^{-1} varied greatly in all five forests having minimum diversity in Sagma forest and maximum in Adheri forest (**Table 8**). The stand density of trees of the present study forest was compared with some tropical forests of Nepal and India. The tree density values were found higher than the values, 226.93 indi. ha^{-1}, 453-550 indi. ha^{-1} and 234-466 indi. ha^{-1} reported by Acharya & Shresth (2011) and Gautam & Mandal (2016) respectively. While the tree density values are lower than the values 2189 indi. ha-1, 1125 indi. ha-1, 1092-1153 indi. ha^{-1} reported by Shrestha, (1997), Duwadee *et al*. (2002), and Bashyal (2005) respectively. On the otherhand, the values of tree density are within the range of 493-1470 indi. ha^{-1} reported by Gairola *et al*. (2011) respectively.

Density-girth class relationship

The distribution pattern of tree species density in different girth classes are presented in **Figure 13**. The distinct difference in density and girth class distribution was observed in five different forests. There was not presence of large GBH trees (>300 cm girth class) in Murchungi (800 m) and Adheri forest (1000 m). The density of trees was high in 10-50 cm girth class, which declined gradually up to >300cm girth class almost in all forests. At Bhaunne forest, 51 % of density contributed by trees with 10-50cm girth class to the total density. At Raja-Rani (500 m), Murchungi (800 m), Adheri (1000 m) and Sagma forests (1200 m), trees with 10-50 cm girth class contributed 67 %, 42%, 47% and 55 % respectively to the total tree density in the respective forest (**Figure 14**).

The analysis revealed the highest number of tree species were present in trees of 10-50 cm girth class in all the forest except Bhaunne forest (low elevated forest, 200 m). Bhaunne forest larger number of tree species was found in trees of 50-100 cm girth class. Less number of trees of 10-50 cm girth classes in Bhaunne (low land forest, 200 m) forest was due to pressure of human activities; like due to selective felling of lower girth class plants, grazzing cattles etc although disturbances parameters was not considered in this study. Whereas, larger number of tree species with 50-100 cm girth class may be due to fertile soil, high biomass and suitable climatic conditions (Gautam & Mandal, 2018; Sharma *et al*., 2020).

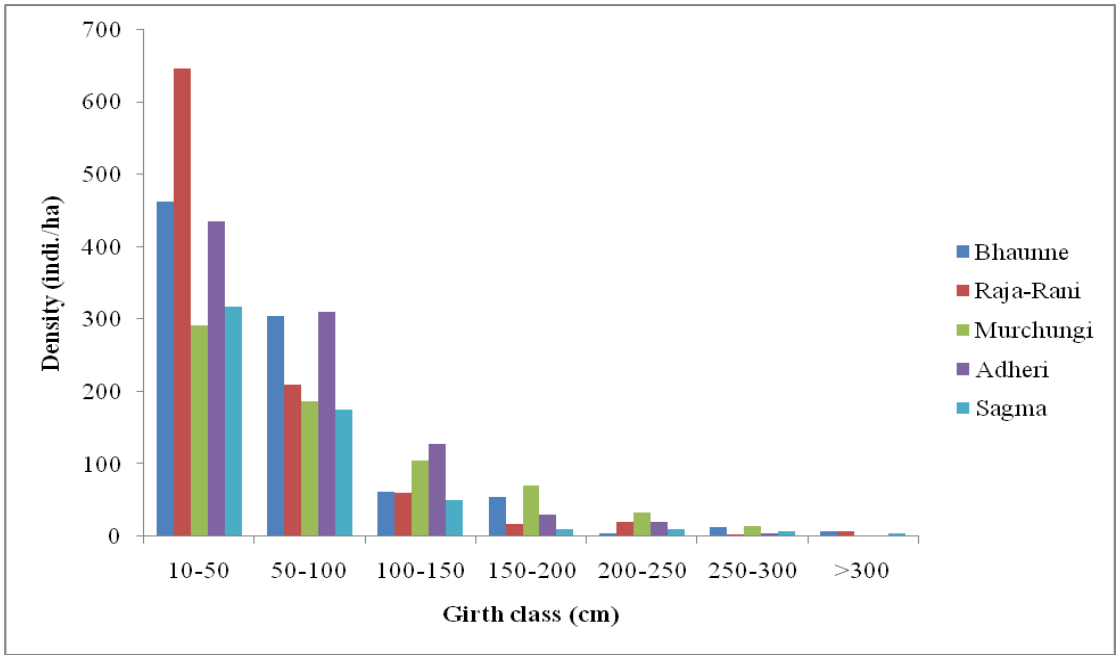


Figure 13: Density of trees in different girth classes in the Bhaunne, Raja-Rani, Murchungi, Adheri and Sagma forest stands of Morang district, eastern Nepal. Girth classes (cm) are: 10-50, 50-100, 100-150, 150-200, 200-250, 250-300 and >300.

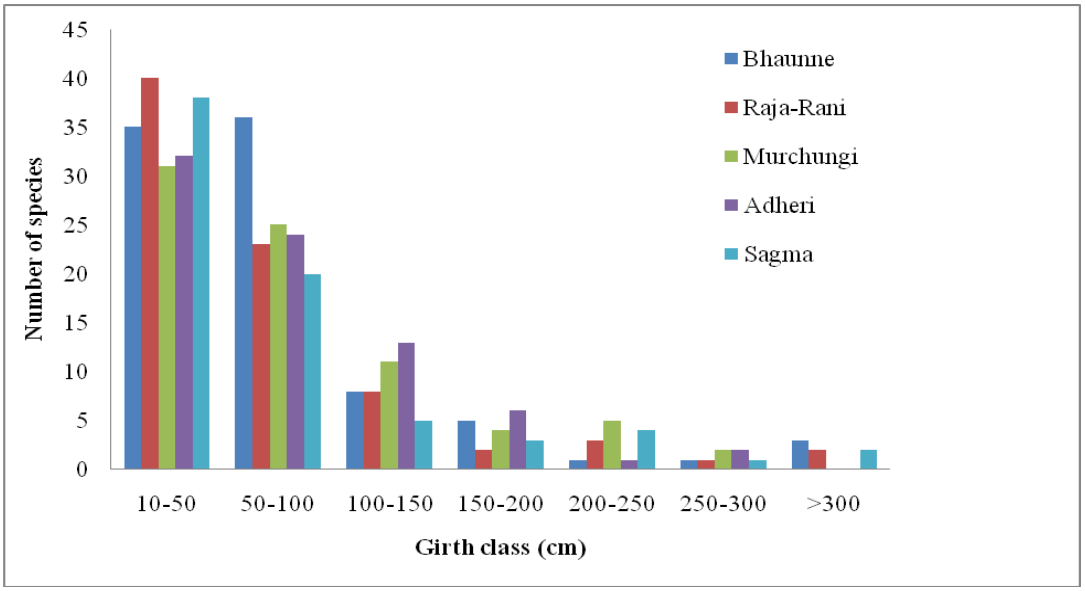


Figure 14: Distribution of species content of trees in different girth classes in the Bhaunne, Raja-Rani, Murchungi, Adheri and Sagma forest stands of Morang district, eastern Nepal. Girth classes (cm) are: 10-50, 50-100, 100-150, 150-200, 200-250, 250-300 and >300.

Basal area of trees

Basal area of trees contributes to the volume or biomass of trees. The basal area of trees ranged between 34.35 m^2 ha^{-1} and 61.20 m^2 ha^{-1} along the five forest stands with minimum value in Sagma forest and maximum value in Murchungi forest (**Table 8**). The basal area values of tree are lower than the values, 67.1 m^2 ha^{-1}, 132.52 m^2 ha^{-1} and 163.66 m^2 ha^{-1} reported by (Mandal (1999), Sukumaran *et al*. (2018) and Chettry *et al*. (2021) respectively. Whereas, the values are comparable with the values reported by Giri *et al*. (2011) and higher than the values, 20.5 m^2 ha^{-1} and 12.98-3363 m^2 ha^{-1} revealed by Raha *et al*. (2020) and Naidu & Kumar (2016). While the values are within the range of 18.60- 104.6 m^2 ha^{-1} reported by Bhuyan *et al*. (2003). This happens due to differences in girth and density of trees. The basal area (54.30 m^2 ha^{-1}) of low land forest i.e Baunne forest was within the range of the values 52.3- 111.6 m^2 ha^{-1} reported by Gautam & Mandal (2016) in tropical moist forest of eastern Nepal.

4.1.2 Diversity indices

Values of diversity indices of herbs, shrubs and trees are mentioned in **Table 14**. The Shannon-Wiener index increased with an increase in number of species. The higher Shannon-Wiener index compared to the Simpson's index, indicates an inverse relationship between these two indices.

In herbs layer, Species richness (*SR*) value ranged from 14.81-19.3. Shannon-Wiener index for herbs ranged from 3.58 to 3.79 in the forest stand, which is higher than Shannon-Wiener value reported by (Devi & Yadava, 2006). Species richness and Shannon-Wiener index of herbs were maximum (19.3 and 3.79 respectively) in Bhaunne forest (**Table 14**). The herb species richness was higher in Bhaunne which may be due to high soil nutrients and high temperature, which adds up in germination of species. Soil nutrient content and plant species have a positive correlation (Dybzinski *et al*., 2008; Rodrigues *et al*., 2018). On the other hand, lower herb species richness in Murchungi forest might be due to low organic matter and soil nutrients which tended to suppress the germination, growth and development of species (Furey & Tilman, 2021).

The values of herb species richness are comparable with the values reported by Acharya & Shrestha (2011). These parameters exhibited more or less U-shaped trend with the forests at different elevation from Bhaunne to Sagma having lower values in

middle elevated (Murchungi-800 m) forest. Concentration of dominance ranged between 0.03 and 0.92 with maximum value in Bhaunne forest. The values of concentration of dominance of herbs are comparable with the values reported by Devi & Yadava (2006) and Acharya & Shrestha (2011). Simpson's evenness ranged between 0.92 and 1.87, with minimum value at both Bhaunne and Sagma forest and the maximum value at Murchungi forest.

In case of shrub, species richness values (2.09-3.86) are lower than the values reported by (Swamy *et al*., 2010). Shub species richness showed increasing trend along the increasing elevation from Bhaunne to Sagma forest. Simpson's evenness values showed unimodal trend across the forest with maximum value (0.85) at Murchungi forest. Shannon-Wiener index of shrubs ranged between 2.2 and 2.98, exhibiting increasing trend with the elevation. The values of Shannon-Wiener index of shrubs are comparable with value reported by Devi & Yadava (2006), Swamy *et al*. (2010) and Acharya & Shrestha (2011). Conversely, its concentration of dominance ranged between 0.08 to 0.19, it showed decreasing trend with increasing elevation (**Table 13**). Values of shrubs are greater than the values reported by Devi & Yadava (2006) and Swamy *et al*. (2010).

In case of trees, concentration of dominance values ranged from 0.08 to 0.46, which are lower than Naidu & Kumar (2016) and comparable with the values reported Shahid & Joshi (2016). The increasing of shrub species richness and decreasing of herb tree species richness are regulated by light and soil properties (Dybzinski *et al*., 2008). Light availability to herb and shrub communities may affect considerably the relationship because the growth of understory communities is usually highly affected by light availability and density of volume of over story canopy. A positive relationship between soil fertility and species richness of herbs was reported by Nadeau & Sullivan (2015), which is in support of present study. Species richness and Shannon -Weiner index of shrub species was high in Sagma forest due to open canopy.

Table 14: Diversity indices of different growth forms in five forests located at different elevations in Morang district, eastern Nepal.

Parameters	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
Species richness (*d*)					
Herbs	19.3	16.95	14.81	15.23	15.05
Shrubs	2.09	2.56	2.82	3.21	3.86
Trees	8.48	7.28	7.06	6.11	5.94
Evenness index (***e***)					
Herbs	0.92	1.84	1.87	0.93	0.92
Shrubs	0.72	0.78	0.85	0.84	0.8
Trees	0.76	0.72	0.72	0.59	0.88
Concentration of dominance (*cd*)					
Herbs	0.92	0.06	0.03	0.04	0.03
Shrubs	0.19	0.13	0.08	0.08	0.1
Trees	0.12	0.11	0.16	0.46	0.08
Shannon-Wiener index (*H'*)					
Herbs	3.79	3.67	3.65	3.58	3.78
Shrubs	2.2	2.45	2.91	2.9	2.98
Trees	3.08	2.85	2.77	2.22	3.12

Tree species richness ranged between 5.94 and 8.48 across the forests. Lowest species richness value was found in Sagma forest and highest value was in Bhaunne forest. Tree species show decreasing trend from lower to higher elevation forest, with maximum number of tree species in Bhaunne forest and minimum number of tree species in Sagma forest which may be due to effect of environmental factor, like elevation, precipitation and temperature. Species richness values of trees is lower than the values (10.04-11.24) reported by Naidu & Kumar (2016) and higher than the values reported by Reddy *et al*. (2011) and Chettry *et al*. (2021).

Similarly, concentration of dominance in case of tree was high in Adheri forest (0.46) and low in Sagma forest (0.08). Its value decreased from Bhaunne to Raja-Rani, then increased up to Adheri forest and again decreased at Sagma forest, showing an irregular trend. Furthermore, both Simpson's evenness and Shannon-Wiener index

were maximum, 0.88 and 3.12 respectively in Sagma forest, whereas their values were minimum 0.59 and 2.22 respectively in Adheri forest (**Table 14**).

Similarly, in case of trees, the Shannon-Wiener values ranged from 2.22 to 3.12 which is comparable with the values (2.0-3.7) reported by Swamy *et al*. (2010) and Naidu & Kumar, (2016), while it is higher than the values reported by Devi & Yadava (2006); Shahid & Joshi (2016), and Chettry *et al*. (2021).

4.1.3 Relationship between species richness and elevation

The total species richness (total number of species) showed statistically significant (D^2=0.13, p<0.01) linear increasing relationship with increasing elevation in the study (**Figure 15 A**). Hence, the proposed hypothesis, "the plant species richness decreases linearly with an increase in elevation" has been rejected. However, this hypothesis may be true for specific plant species richness such as herbs, shrubs and trees.

The herbs species richness (number of herbs species per plot) showed statistically significant (D^2=0.11, p<0.01) linearly inclined relationship with increasing elevation (**Figure 15 D**). This finding was aligned with total species richness. The shrub species richness (number of shrub species) showed statistically significant (D^2=0.61, p<0) inclined relationship with increasing elevation (**Figure 15 C**). Similarly, Tree species richness (number of tree species) statistically significant (D^2=0.12, p<0.01) linearly declined relationship with increasing elevation (**Figure 15B**).

The widely documented monotonic decline in species richness with increasing elevation (Brown 1988; Stevens, 1992) contrasts with the current findings. Bhattarai *et al*. (2004) similarly reported a declining trend in central Nepal, as did Körner (2007) and Grytnes (2003). However, studies by Rahbek (1997), Vetaas & Grytnes (2002), and Beckman *et al*. (2004) observed an elevational incline in species richness, which aligns with the present study but with different underlying justifications. In this research, total species richness followed the same incline pattern as shrub and herb richness, while tree richness did not, indicating that shrub and herb diversity were the primary contributors to overall richness. A probable explanation for this incline pattern is the more humid, tropical-to-temperate eastern climate, which may have particularly favored shrub and herb diversity in the study area.

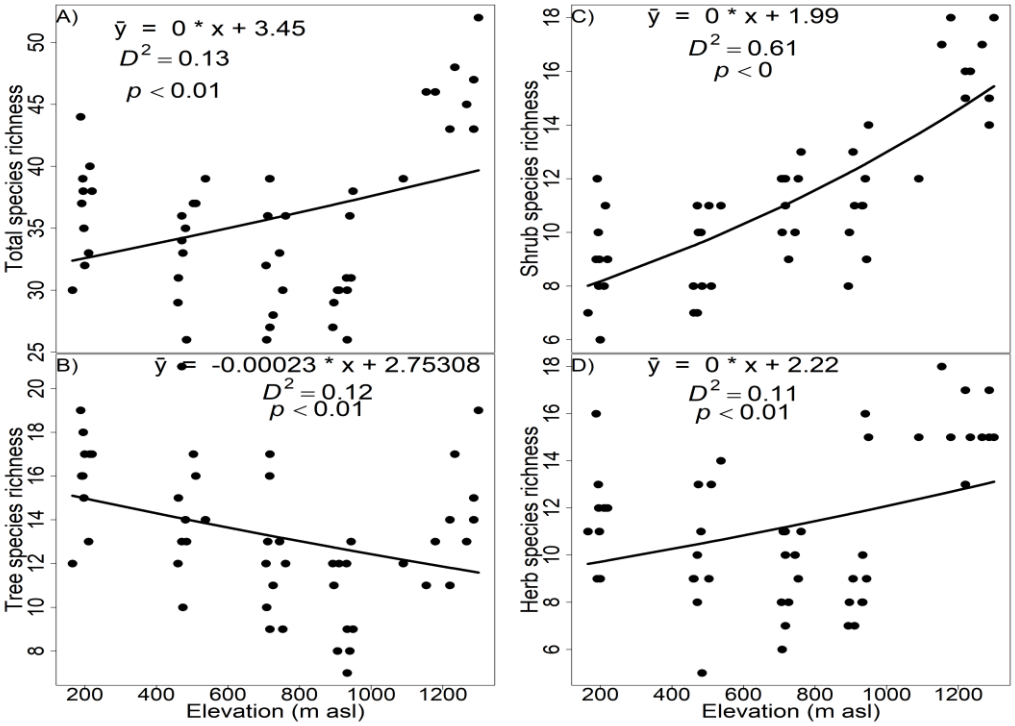


Figure 15: The relationship between species richness and elevation. The fitted line is the linear first order after the generalized linear model (glm). A) Total species richness (combining all life forms), B) tree species richness, C) shrub species richness and D) herb species richness. Equation within each figure denotes the equation of the fitted line, D^2 represents the pseudo R^2 of the selected model and their statistical significance is denoted by the *p-value*.

The hypothesis that plant species richness decreases with increasing elevation was not fully supported by the findings of this study. While the commonly observed trend of declining species richness with elevation (Brown 1988; Stevens 1992) aligns with some previous research (e.g., Bhattarai *et al.*, 2004; Körner, 2007; Grytnes 2003), the results of this study revealed a more complex relationship. Specifically, total species richness exhibited an inclining pattern with elevation, which was consistent with some studies (e.g., Rahbek, 1997; Vetaas & Grytnes, 2002; Beckman *et al.*, 2004), but diverged from the conventional decline. This inclining pattern was particularly evident for shrub and herb richness, while tree richness did not follow the same trend. These findings suggest that in the study area, factors such as the more humid, tropical-to-temperate eastern climate may have favored shrub and herb diversity, contributing to the observed increase in species richness with elevation. Therefore, the results indicate that while the general hypothesis of decreasing species richness with elevation holds in many contexts, this study highlights the need to consider local

climatic and ecological conditions that may influence species richness patterns differently. Further research is necessary to explore these factors in various contexts to fully understand the complexities of elevational gradients in plant diversity.

The widely documented monotonic decline in species richness with increasing elevation (Brown 1988, Stevens 1992) contrasts with the current findings. Bhattarai et al. (2004) similarly reported a declining trend in central Nepal, as did Körner (2007) and Grytnes (2003). However, studies by Rahbek (1997), Vetaas and Grytnes (2002), and Beckman et al. (2004) observed an elevational incline in species richness, which aligns with the present study but with different underlying justifications. In this research, total species richness followed the same incline pattern as shrub and herb richness, while tree richness did not, indicating that shrub and herb diversity were the primary contributors to overall richness. A plausible explanation for this incline pattern is the more humid, tropical-to-temperate eastern climate, which may have particularly favored shrub and herb diversity in the study are

4.1.4 Pairwise comparison of species richness among forests

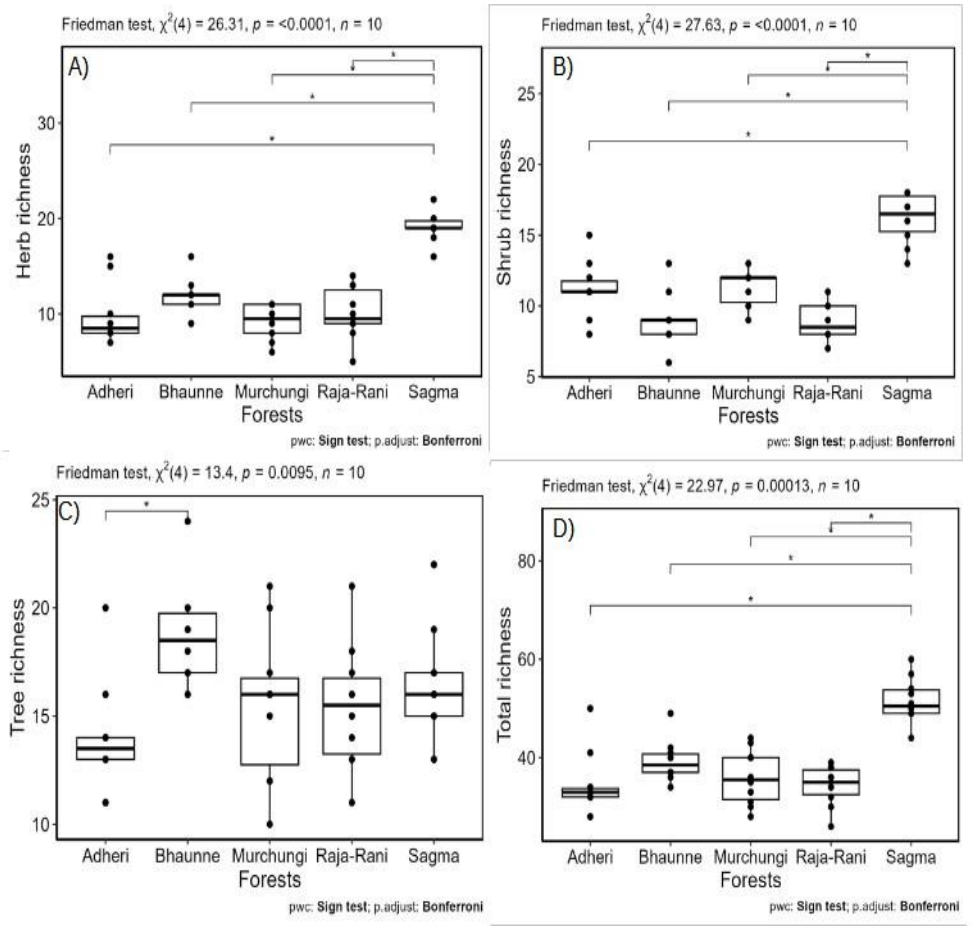
Friedman test showed herb species richness was significantly (p=<0.0001) different between Bhaunne and Sagma, Raja-Rani and Sagma, Murchungi and Sagma and Adheri and Sagma forest.

Shrub species richness of Sagma forest was significantly (p=<0.0001) different with all the other four forests, such as shrub species richness is significantly different between Adheri and Sagma, likewise between Raja-Rani and Sagma forest, Bhaunne and Sagma, Murchungi and Sagma forest.

Tree species richness was significantly (p=0.0095) different between Bhaunne and Adheri forest. Total species richness was significant between the forests; Bhaunne and Sagma, Raja-Rani and Sagma, Murchungi and Sagma, and Adheri and Sagma forest. Total species richness (combing herbs, shrubs and trees) of forest significantly (p value is 0.00013) different between Sagma and Adheri forest, Sagma and Bhaunne forest, Sagma and Murchungi forest and Sagma and Raja-Rani forest (**Figure 16**).

The Sagma forest demonstrates notably higher species richness for total, shrub, and herb categories. Elevation likely exerts a significant influence, as the specific environmental conditions at this elevation, such as cooler temperatures, increased

humidity, and the presence of specialized niches, appear to support a greater diversity of these plant groups. The significant differences revealed by the pairwise comparisons suggest that these high-elevation conditions are particularly favorable in contrast to those of the lower elevation forests. In contrast, tree species richness was found significantly higher in the Bahuune and Adheri forests, situated at 200 m and 1000 m above sea level, respectively. The pairwise comparisons indicated that trees derive greater benefit from the conditions prevalent at these lower elevations, such as warmer temperatures, richer soil profiles, and potentially reduced competition from other vegetation types. These factors likely contribute to more robust tree growth and increased diversity, resulting in significant differences when compared to forests at higher elevations. This interpretation is consistent with findings by Joshi & Joshi (2022), which suggest that trees at lower elevations are better adapted to warmer climates, whereas shrubs and herbs are more suited to the cooler, more stable environments found at higher elevations. The harsher conditions at higher elevations may restrict tree growth, thereby favoring the richness of shrubs and herbs. Conversely, the more favorable conditions at lower elevations likely promote greater tree richness.



Here, Bhaunne:200 m; Raja-Rani: 500 m; Murchungi: 800 m; Adheri: 1000 m; Sagma: 1200 m.

Figure 16: Relationship of richness of: A) Herb, B) Shrub, C) Tree, and D) Total species among forests. Cap lines with '*' represented the statistical significant difference in richness between forests after the pairwise multiple comparison of richness through Friedman tests.

4.1.5 Clustering of species

Clustering was performed to identify similarities (ecologically similar niches) and differences among species. A total of 49 clusters were formed after the cluster analysis of the unique species dataset from Bhaunne forest. The dendrogram (**Figure 17**) revealed statistically significant 49 clusters of species that were exclusively found within the forest plots of Bhaunne. The species *Eclipta prostrata* (*Ecli. pro.*), *Cyperus rotundus* (*Cyp. rot.*), and *Abutilon indicum* (*Abu. in.*) had the highest AU values (100%), indicating a high level of confidence in the first, second, and third clusters (edge numbers: 1, 2, and 3). These three species, located at the lowest level of the dendrogram, exhibit the least dissimilarity and likely share maximum common characteristics. This was consistent with their herbaceous nature and their likely

occurrence in open spaces between forest gaps. These species were enclosed in a red box, as they represented the most reliable and significant cluster.

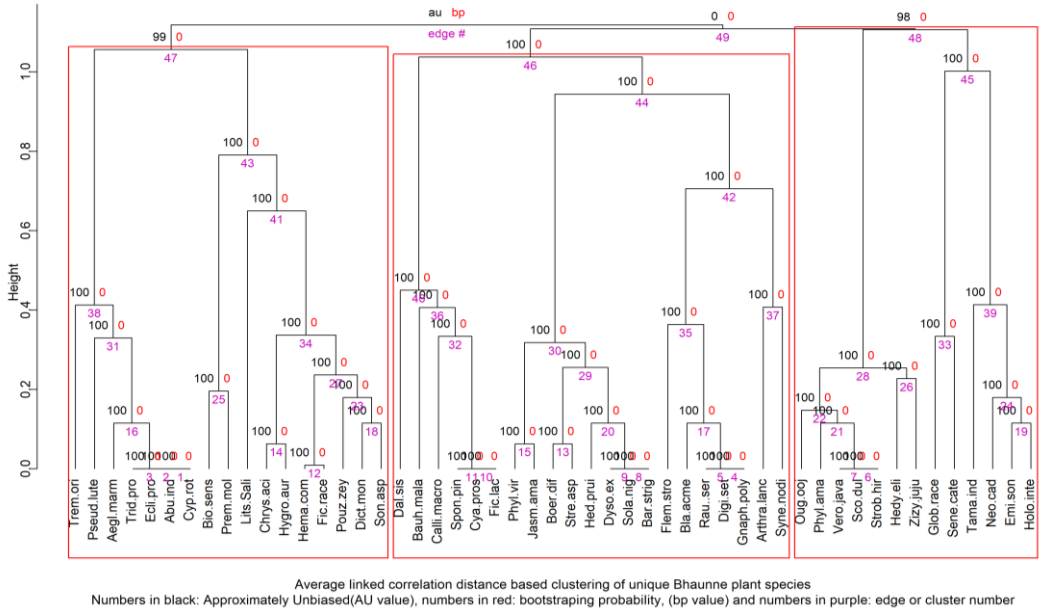


Figure 17: Hierarchical clustering of species with *p*-value (*pvclust*) from Bhaunne forest (200 m) stand of Morang district, eastern Nepal. Full form of each abbreviated plant species name within each cluster has been given at an Appendix-I.

In Raja-Rani forest, 24 unique species dataset formed 22 significant clusters (**Figure 18**). The cluster of species *Curcuma angustifolia (Cur. ang)* and *Debregeasia longifolia (Debre. long.)* formed significant cluster edge 1. Likewise, the species *Floscopa scandens (Flos. sca.)* and *Paramignya monophylla (Para. mono.)* formed significant cluster edge 2 (**Figure 18**). All these four species enclosed within a box were having the highest AU (100) and BP values (3) respectively. Their position was at the lowest level in the dendrogram meaning that they got the highest similarity in term of ecological niches. That was true due to their abundance towards human influenced area with open canopy.

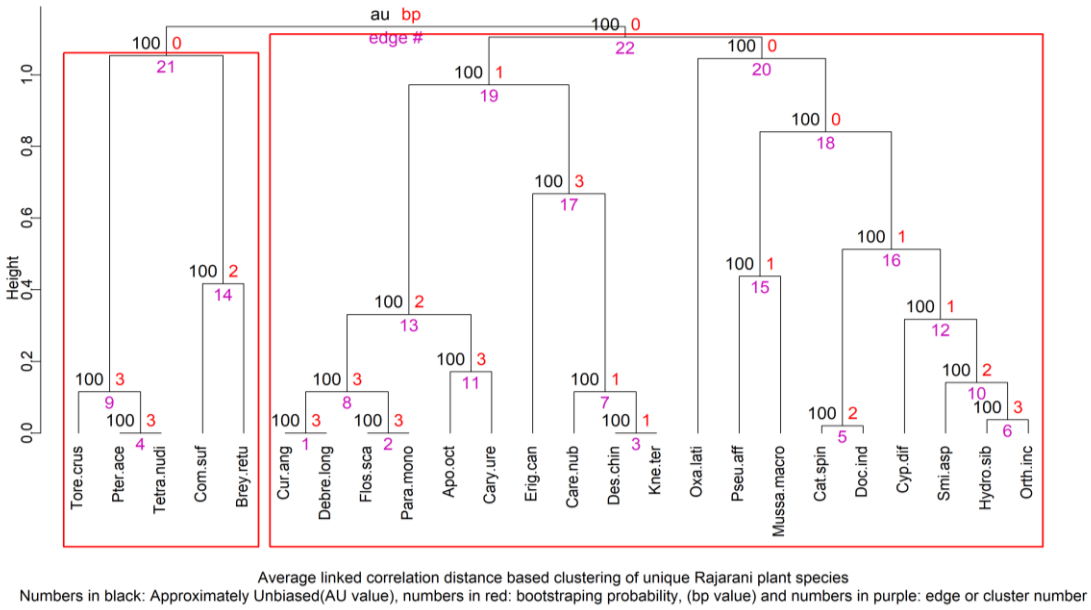


Figure 18: Hierarchical clustering of species with *p*-value (*pvclust*) from Raja-Rani forest (500 m) stand of Morang district, east Nepal.

The *pvclust* diagram (**Figure 19**) represented unique species from Murchungi forest. The dendrogram displayed 13 species, which were grouped into 11 significant clusters. *Dicliptera chinensis (Dicl chin)* and *Murdannia nudiflora (Mur nudi)* were positioned at the bottom-most level, indicating the highest degree of similarity between them. This close association was likely due to their shared characteristics, including their herbaceous growth form and preference for shaded, moist environments. Additionally, both species were subject to intense grazing pressure by cattle, which further contributes to their ecological overlap and the formation of a distinct, significant cluster in the analysis.

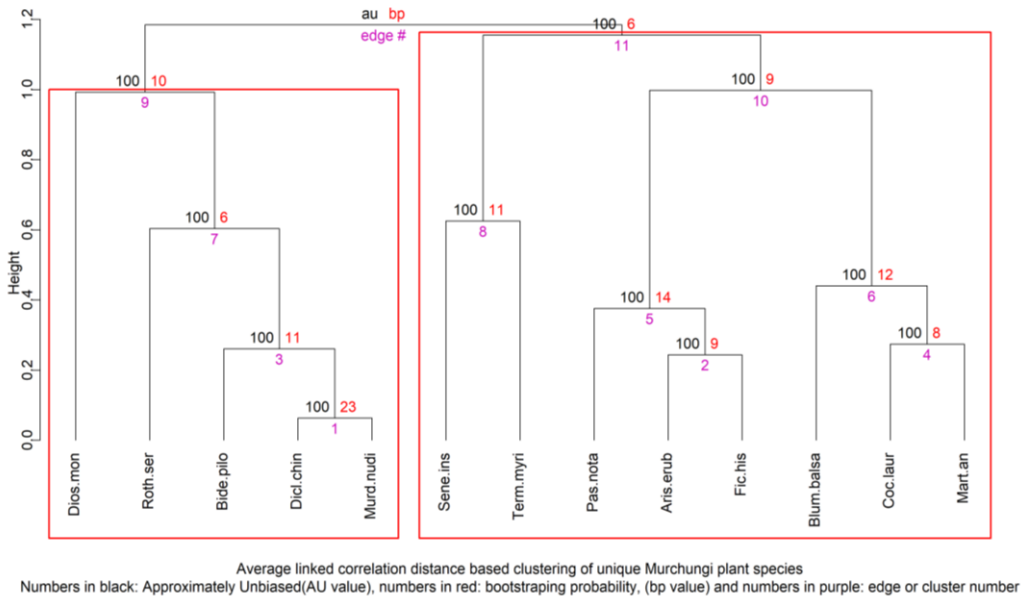


Figure 19: Hierarchical clustering of species with *p*-value (*pvclust*) from Murchungi forest (800 m) stand of Morang district, east Nepal.

A total of 15 significant clusters formed after the *pvcluster* analysis of unique species dataset from Adheri forest (**Figure 20**). A total of 17 species unique to Adheri forest. Species such as *Phragmites karka (Phrag kar)* and *Rhynchoglossum obliquum* (Rhyn obli) belonged to the first significant cluster located at the bottom most in the dendrogram dealt their highest ecological similarity. Both of these species were moister loving, thus growing near canal.

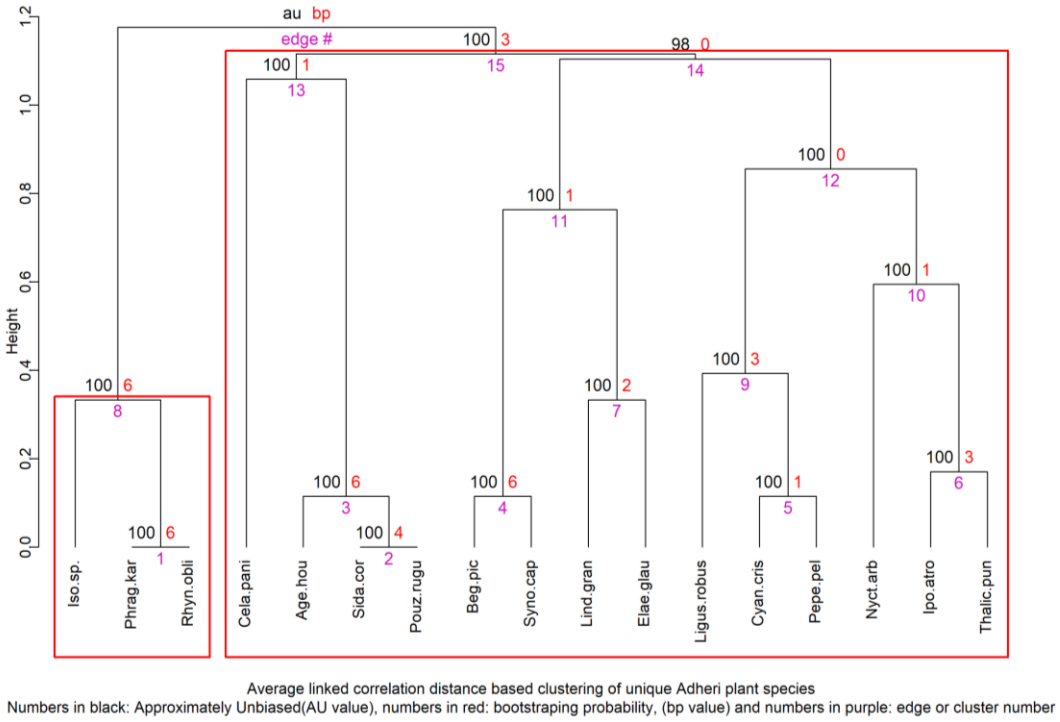


Figure 20: Hierarchical clustering with *p*-value (*pvclust*) of species from Adheri forest stand (1000 m) of Morang district, east Nepal.

A total of 42 clusters formed after the *pvclust* of 44 unique species from Sagma forest dataset (**Figure 21**). The succulent herbaceous, *Elatostema platyphyllum (Ela. pla)* and *Indigofera sp. (Indi.* sp*)* shrub formed a significant cluster of edge number 1. Ecological similarity between them would have due to their similar substratum. The dry rocky habitats favorable to grow *Indigofera* sp. would create micro-habitat suitable to *Elatostema platyphyllum.* These two species together with Boenninghausenia albiflora (Boen. alb) formed an another significant cluster (edge 8). Having similar height with one of arms of edge 1 to Boen. alb would indicate similar ecological micro-habitat. Likewise, five significant edges (1, 8, 17, 26 and 31) formed in this group. Clusters formed above of this box were not significant (**Figure 21**).

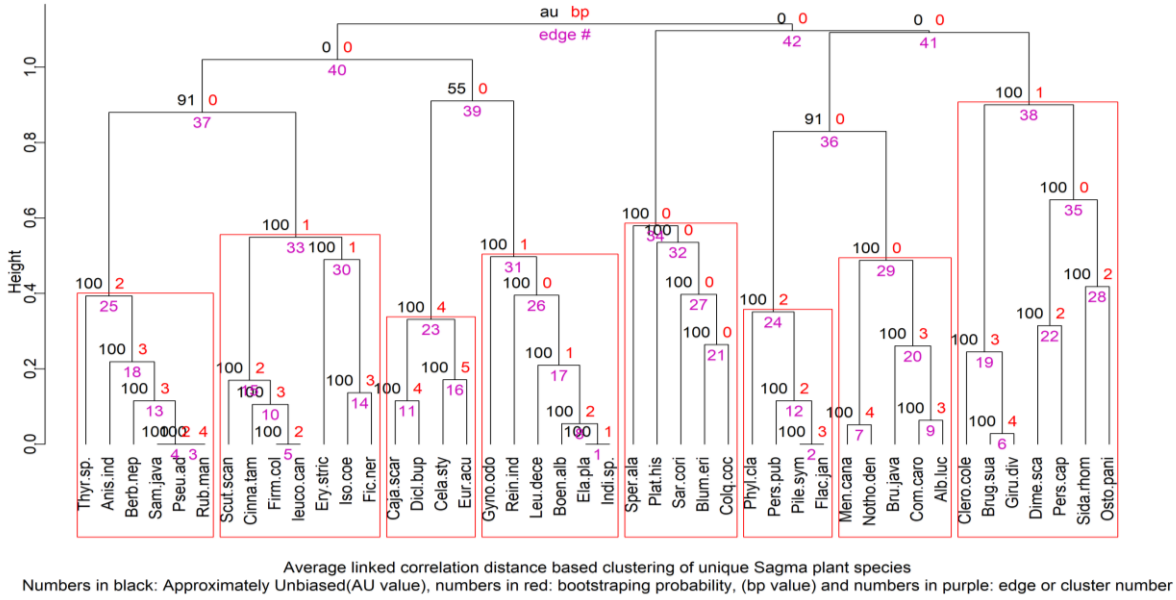


Figure 21: Hierarchical clustering of species with *p*-value (*pvclust*) from Sagma forest stand (1200 m) of Morang district, east Nepal.

Bhaunne was hosting the highest number of unique species (51), followed by Sagma (44). This suggested that these two forests were significant reservoirs of biodiversity by hosting a substantial number of species not found in the other forests, which justified their ecological importance. Although the number of unique species was lower in Raja-Rani, Adheri, and Murchungi, their presence still contributed to the overall biodiversity of the region.

The clustering analysis showed that Bhaunne and Sagma formed the highest number of clusters (49 and 42, respectively), indicating a more complex ecological structure. These clusters likely reflect variations in microhabitats and niche specialization within these forests, suggesting that they support not only a high number of species but also diverse ecological interactions. In contrast, the lower number of clusters in Raja-Rani, Adheri, and Murchungi (22, 14, and 11) respectively suggests less ecological complexity or a more homogeneous environment, with fewer distinct niches and thus fewer species aggregations.

These findings highlighted that both high and low elevation forests (Sagma and Bhaunne) were critical for maintaining biodiversity, due to their significant numbers of unique species and complex clustering patterns. These patterns were likely a result of the distinctive environmental conditions at these elevations, such as variations in

temperature, moisture, and soil composition, which created diverse habitats supporting a wide range of species and ecological interactions. Conversely, the intermediate elevation forests (Raja-Rani, Adheri and Murchungi) showed lower levels of species composition, uniqueness, and clustering, which may reflect less pronounced ecological conditions and fewer opportunities for niche specialization.

These results underscore the importance of conserving both high and low elevation forests due to their unique species and complex ecological structures. The high number of unique species and clusters in these forests highlights their role in maintaining regional biodiversity. Therefore, conservation strategies should prioritize protecting these areas from environmental degradation to preserve their ecological integrity. These findings are consistent with findings of earlier researchers such as Kessler & Schmidt-Lebuhn (2006), Harte & Shaw (1995), and Grytnes & Vetaas (2002), which support the observed patterns of biodiversity along elevational gradients.

4.2 Plant biomass and carbon stock

Bhaunne forest (200 m) possessed maximum tree biomass (796.46 Mg ha^{-1}) and Sagma forest (1200 m) contained minimum tree biomass (265.23 Mg ha^{-1}). Even total stand biomass was also accounted to be maximum (815.86 Mg ha^{-1}) in Bhaunne forest (low elevation) and minimum (299.96 Mg ha^{-1}) in Sagma forest i.e., in high elevation (**Table 15**). Conversely, the shrubs and herbs biomass were maximum in Sagma forest to their higher density and lower density of tree species. Among different components of tree, maximum contribution was made by bole and minimum contribution made by leaf in all the forests. Total of shrubs and herbs biomass were highest (16.38 Mg ha^{-1} and 8.65 Mg ha^{-1} respectively) in Sagma forest and least (8.48 Mg ha^{-1} and 1.80 Mg ha^{-1} respectively) in Adheri forest**.**

The total plant biomass varied among different growth forms and in the different forests located along different elevations. The biomass allocation in different components viz. bole, branch, twig, leaf and coarse root of tree, similarly, stem, leaf and root of shrubs and herbs, fine root biomass are mentioned in **Table 15**. Trees, shrubs, and herbs comprised 97.62 %, 1.04 %, and 0.45 % of total biomass in Bhaunne forest, 93.09%, 3.34 %, and 0.49 % of total biomass in Raja-Rani forest respectively. Likewise, 94.64 %, 2.37 %, and 0.34 % in Murchungi forest, 96.18 %,

1.63 %, and 0.34 % in Adheri forest, and 88.45 %, 5.46% and 2.88 % in Sagma forest respectively. Stand fine root contributed 0.87%, 3.07 %, 2.63%, 1.83% and 3.19% to the total biomass in Bhaunne, Raja-Rani, Murchungi, Adheri, and Sagma forest respectively.

Component wise percentage allocation of biomass in tree and shrubs are mentioned in **Table 16**. In both cases percentage allocation of biomass was higher in the Bole and Stem components. In the case of trees, allocation was in the order of Bole > Branch > Twig > Leaf in the above ground part. Among shrubs maximum contribution was shown by stem biomass which ranged from 44% to 53%, with maximum share in Sagma forest and minimum in Bhaunne forest. Likewise, minimum contribution was seen in foliage which ranged from 14% to 20 % among the forests.

Total C stock varied distinctly among the forest stands located at different elevations (**Table 17**). Allocation of carbon stock is qualified by the allocation of biomass in different components. As per the trend in biomass allocation, carbon stock also showed the same trend,

Bole > Branch > Twig > Leaf in the aboveground part.

Total carbon stock including trees, shrubs, herbs and fine root ranged between 140.19 Mg C ha^{-1} and 333.63 Mg C $ha^{-1,}$ minimum in Sagma forest located at high elevation and maximum in Bhaunne forest located at lowest elevation. It indicates that plant biomass as well as carbon stock was highest at the forest of lower elevation. It indicates that plant biomass as well as carbon stock was highest at the forest of lower elevation. Reverse trend was seen in the case of shrubs, which was minimum 2.64 Mg C ha^{-1} at Bhaunne forest and maximum carbon stock was 7.71 Mg C ha^{-1} at Sagma forest (higher elevation) which contains maximum shrub biomass.

Table 15: Stand biomass (Mg ha^{-1} ± SE) of five forests located at different elevations in Morang district, eastern Nepal.

Forest Components	stands	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
Trees	**Bole**	514.29^{a} ± 67.50	230.02^{a} ± 38.15	336.93^{a} ± 44.27	286.04^{a} ± 36.69	154.33^{a} ± 42.15
	Branch	70.16^{ab} ± 7.35	46.69^{ab} ± 7.01	73.44^{a} ± 7.51	66.10^{ab} ± 6.60	38.37^{b} ± 8.14
	Twig	30.67^{ab} ± 6.30	17.89^{ab} ± 2.78	28.06^{b} ± 3.16	26.27^{bc} ± 2.71	10.51^{a} ± 1.57
	Leaf	16.99^{abc} ± 1.74	11.41^{abc} ± 1.59	17.37^{b} ± 1.86	17.92^{c} ± 1.47	7.29^{a} ± 1.16
	Course	164.35^{ab} ± 45.13	79.56^{a} ± 12.84	118.51^{ab} ± 14.7	103.05^{c} ± 12.31	54.73 ^{ab}± 13.35
	Root	**796.46^{ab} ± 75.72**	**385.57^{ab} ± 64.23**	**574.31^{a} ± 68.23**	**499.38^{ab} ± 62.64**	**265.23^{b} ± 35.72**
	Total					
Shrubs	**Stem**	3.79^{a} ± 0.60	7.17^{a} ± 1.05	7.29^{a} ± 1.90	4.15^{a} ± 0.70	8.58^{a} ± 1.10
	Leaf	1.50^{ac} ± 0.18	2.07^{abc} ± 0.25	2.01^{abc} ± 0.30	1.70^{c} ± 0.18	3.01^{b} ± 0.18
	Root	3.24^{ab} ± 0.6	4.61^{ab} ± 0.50	5.11^{ab} ± 1.33	2.63^{a} ± 0.33	4.79^{b} ± 0.55
	Total	**8.53^{ab} ± 1.21**	**13.85^{ab} ± 1.79**	**14.41^{ab} ± 3.5**	**8.48^{b} ± 1.14**	**16.38^{a} ± 1.76**
Herbs*		3.73^{a}±3.35	2.04^{ac}±1.85	2.09^{ac} ± 1.89	1.80^{ac} ± 1.52	8.65^{b} ± 7.73
Stand fine root		7.14^{a}± 0.84	12.73^{a}± 1.43	16.00^{a} ± 2.69	9.54^{a} ± 0.83	9.70^{a} ± 1.42
Total Stand vegetation		**815.86**	**414.19**	**606.81**	**519.20**	**299.96**

***Aboveground part;** Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

Table 16: Total biomass (Mg ha^{-1}) of trees and shrubs and its distribution (%) in different components in five forests of Morang district, eastern Nepal.

Life- form/Components		Forest stands				
		Bhaunne (200 m)	**Raja-Rani (500 m)**	**Murchungi (800 m)**	**Adheri (1000 m)**	**Sagma (1200 m)**
Trees		796.46 ±218.72	385.57 ±62.23	574.31 ±71.23	499.38 ±59.64	265.23 ±64.72
	Bole (%)	64	60	59	57	58
	Branch (%)	9	12	13	13	14
	Twig (%)	4	5	5	5	4
	Leaf (%)	2	3	3	4	3
	Course Root (%)	21	20	20	21	21
Shrubs		8.53 ± 1.21	13.85 ± .79	14.41 ± 3.5	8.48 ±1.14	16.38 ± 1.76
	Stem (%)	44	52	51	49	53
	Leaf (%)	18	15	14	20	18
	Root (%)	38	33	35	31	29

Higher stand biomass and carbon stock at low elevation (200 m) i.e. at Bhaunne forest. This may be due to higher soil organic matter, soil moisture and temperature at low elevation, which collectively enhance the biomass production and so also the carbon storage. Further species with larger girth, including *Shorea robusta*, are also responsible for higher biomass and carbon stock (Baral *et al*., 2009). Contrary to the results of our study, a number of other studies (Shrestha & Singh, 2008; Mwakisunga & Majule, 2012; Gautam & Mandal, 2016; Bohara *et al*., 2021) have asserted that higher plant biomass is caused by an increase in tree density. While the composition of various species, dominated by *Schima wallichii*, may be the cause of a reduced carbon pool in Sagma forest, consistent with findings from Khanal *et al*. (2008).

As the elevation increases the values of biomass and carbon stock in biomass decrease which may be due to low turnover of soil organic matter in cold environment. As the elevation increases the biomass and carbon stock values in herbs, shrubs and trees showed strong variation. In the tree component it was maximum at low elevated stands and decreases to the high elevated sites due to decrease in tree density and its basal area. On the other hand, in shrubs and herbs the biomass and carbon stocks were

maximum at high elevated Sagma forest, which is due to high value of density to these growth forms.

Carbon stock was found higher in big trees with greater DBH because bigger trees would have high stem volume, high basal area due to large diameter (Chand *et al*., 2018). Decreased biomass at high elevation forest is attributed to lower tree density and size. Biomass and carbon stocks are influenced by species, type, canopy cover, stand structure, and elevation (Xu *et al*., 2020; Thapa-Magar & Shrestha, 2015).

Table 17: Component wise carbon stock (Mg C·ha^{-1}) in different growth forms and in fine roots in five forests located along elevation gradient in Morang district, eastern Nepal

Growth -form	Components	Forest stands				
		Bhaunne (200 m)	**Raja-Rani (500 m)**	**Murchungi (800 m)**	**Adheri (1000 m)**	**Sagma (1200 m)**
Trees	Bole	207.39	103.89	157.80	82.00	72.54
	Branch	30.63	22.72	34.15	26.55	18.35
	Twig	14.77	7.93	13.28	11.04	5.06
	Leaf	6.66	5.27	8.08	7.53	3.16
	Course Root	67.46	36.35	55.46	33.05	25.77
	Total	**326.91**	**176.16**	**268.77**	**160.17**	**124.88**
Shrubs	Stem	1.74	3.31	3.50	1.73	4.08
	Leaf	0.66	0.96	0.95	0.76	1.40
	Root	0.24	1.36	2.33	1.03	2.23
	Total	**2.64**	**5.63**	**6.78**	**3.52**	**7.71**
Herbs		1.18	0.60	0.57	0.77	3.70
Fine root		2.90	4.10	7.00	4.20	3.90
Total		**333.63**	**186.49**	**283.12**	**168.66**	**140.19**

The above ground source of carbon contributed larger percentage to the total carbon. The highest tree biomass of Bhaunne (low elevation) forest gives highest carbon stock which was higher than other dry forests of the Eastern Ghats, like the Kolli Hills of the Eastern Ghats (Ramachandran *et al*., 2007). Total of shrubs and herbs biomass were highest in Sagma forest due to moderate disturbances which cause canopy gap and enough light passes to enhance maximum diversity of herbs and shrubs (Gautam & Mandal, 2016). In the Adheri forest, the least biomass of shrubs and herbs could be due to highest tree densities (Joshi & Ghose, 2014; Reddy *et al*., 2011).

In Central Himalayan forests, aboveground biomass of tree species increased at higher elevation due to the dominance of mature, large trees compared to lower elevations (Adhikari *et al*., 1995). It differs from the results of the present study where aboveground biomass and carbon stock was maximum at the forest of lower elevation (Bhaunne forest). However, the Murchungi forest located at 800 m elevation, contains second highest value of plant biomass and carbon stock. The tree layer contributed the majority of the total aboveground biomass which ranges between 88.45% to 97.62%, it is close to the results reported by Thokchom & Yadava (2017).

There is great variation in aboveground carbon stock across different forest stands, the reason of variation may be soil nutrients which affect to tropical forest carbon (Lewis *et al*., 2013; Hofhansl *et al*., 2020). The larger contribution of C stock (50% and 68 %) was seen in aboveground biomass. Then again among the components of tree and shrubs, largest C stock were shared by bole or stem. Sheikh *et al.* (2020) also recorded a significant ($p < 0.001$) difference between bole and branch biomass.

The decrease in biomass with an increase in elevation may also be attributed to a decrease in mean diameter with elevation. Increasing elevation may affect tree growth rates and stand structure because of reduced air and soil temperatures and alterations in nutrient availability and soil chemistry (Drollinger *et al*., 2017; Mcvicar & Scientific, 2013). Across all of the forest, there was irregular trends in plant biomass and carbon stock. Factors influencing forest biomass and Carbon stocks include ecological differences, geographical features, climatic conditions, species and soil composition, variation in tree density, forest structure and variation in diameter of trees (Borah *et al*., 2013; Bordin *et al*., 2021; Melkania, 2009).

4.2.1 Multiple pairwise comparisons of herbs, shrubs and trees biomass among the forests

Bonferonni analysis in three variables; herbs, shrubs and trees biomass showed the distribution of their total biomass was distinctive in five different forest. In case of herbs, the total biomass was significantly different ($p =< 0.001$) between Bhaunne and Sagma forest, Raja-Rani and Sagma forest, Murchungi and Sagma forest and Adheri and Sagma forest (**Figure 22 A**).

In case of shrub biomass, there was significant differences (p = 0.017) occurred between Adheri and Sagma forest (**Figure 22 B**). The significant differences (p = 0.021) in tree biomass were observed between Murchungi and Sagma forest only (**Figure 22 C**).

The study of biomass and soil properties across five forests: Bhaunne, Raja-Rani, Murchungi, Adheri, and Sagma revealed how elevation shapes these ecosystems. The analysis highlighted there were significant differences in biomass among herb, shrub, and tree layers, particularly when comparing Sagma to other forests, and underscores the crucial role of soil properties in these patterns.

Herb biomass exhibited significant differences across all forests, especially when comparing Sagma with the other four forests. This suggests that unique environmental conditions of Sagma possibly related to microclimate, soil composition, nutrients, pH or forest management. They significantly influence the herb growth. The observed increase in herb biomass with elevation aligns with well-established ecological principles, where cooler temperatures and higher moisture levels at higher elevations favour the growth of herbaceous plants. This trend is supported by recent studies, which show that elevation gradients can lead to distinct changes in biomass distribution due to variations in microclimate and nutrient availability (Gairola *et al*., 2021; Körner, 2007).

Unlike herb biomass, shrub biomass showed significant differences only between Adheri and Sagma. This suggests that specific local conditions or management practices might be influencing shrub growth more than elevation itself. Although shrub biomass generally increased with elevation, the trend was not statistically significant, indicating that other factors: such as soil composition, sunlight availability, or competition with other vegetation may play a more crucial role (Loydi *et al*., 2013). This finding is consistent with the understanding that shrubs, while sensitive to elevation, may also be heavily influenced by local environmental factors.

Tree biomass exhibited a significant decrease with elevation, particularly between Murchungi and Sagma. This inverse relationship is consistent with ecological observations that trees at higher elevations often face harsher conditions, such as lower temperatures, increased wind exposure, and shorter growing seasons. These factors can limit tree growth and biomass accumulation, making it difficult for trees to

thrive at higher elevations (Moser *et al*., 2011). Recent research emphasizes that elevation is a critical determinant of tree distribution and biomass, especially in mountainous regions where temperature and nutrient availability can vary significantly (Conway & Danby, 2022).

The study also revealed significant negative correlations between elevation and soil properties namely: soil phosphorus, pH, and moisture. This is consistent with findings from other mountainous regions, where higher elevations often have more acidic soils with lower nutrient availability, partly due to slower organic matter decomposition and increased leaching (Wang *et al*., 2019). The decrease in soil moisture with elevation could be attributed to factors like increased runoff and reduced soil depth, which limit the soil's ability to retain water (Schlesinger & Bernhardt, 2020).

These findings align with broader ecological theories and recent studies, which emphasize that elevation gradients lead to complex shifts in vegetation composition and structure due to changes in climate and soil properties. As such, understanding the interplay between these factors is crucial for predicting how forest ecosystems might respond to environmental changes, particularly in the context of global climate change.

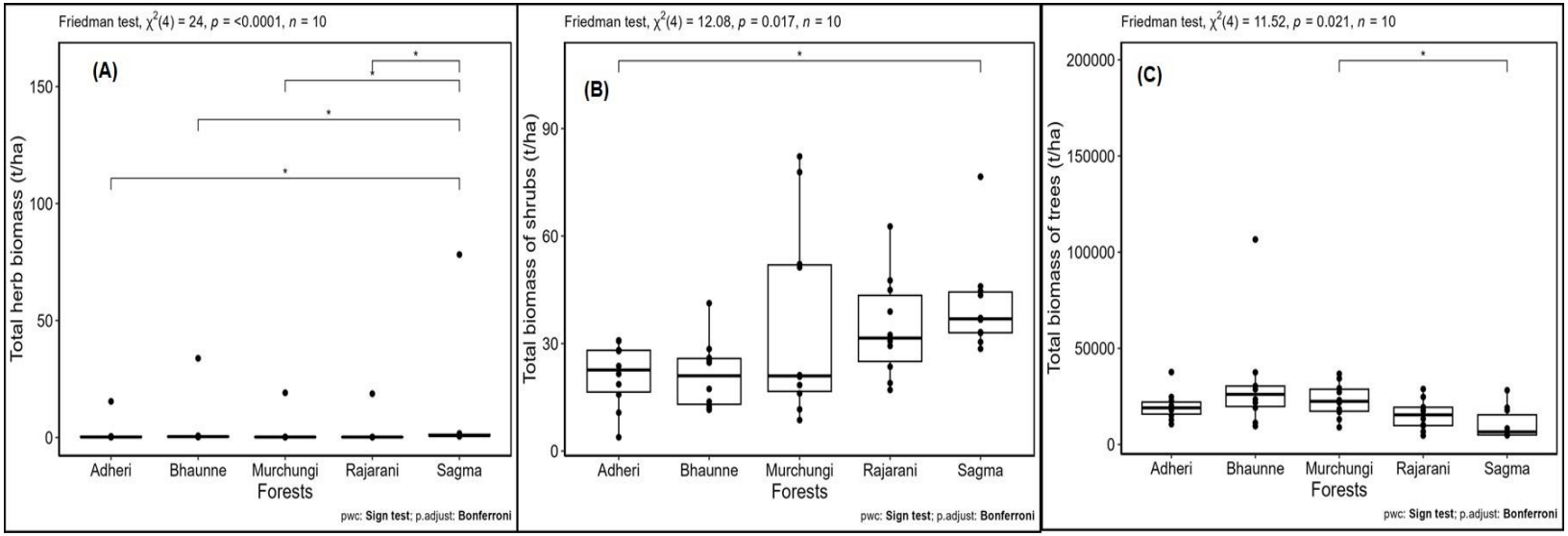


Figure 22: Relationship of biomass of: A) herb, B) shrubs and C) trees in five different forests. Cap line with "*" denoted the statistical significant difference of biomass between forests after Friedman's multiple comparison tests).

4.2.2 Relationship between biomass and elevation

A statistically significant inverse relationship between elevation and both total biomass and tree biomass ($p < 0.05$) indicates a decrease in biomass with increasing elevation (**Figure 23 A, B**). This finding aligns with recent studies (Smith *et al*., 2022; Zhao *et al*., 2023) suggesting that the higher elevations often impose harsher environmental conditions, such as lower temperatures and reduced soil fertility, which can limit tree growth and overall biomass accumulation. Conversely, a significant positive relationship was observed between elevation and herb biomass (**Figure 23 D**), suggesting an increase in herbaceous species at higher elevations. This could be attributed to the adaptability of herbaceous plants to the cooler and more open environments typically found at higher elevations (Jones & Williams, 2021). For shrub biomass, an inclining trend with elevation was noted, but it was not statistically significant (**Figure 23 C**), which may reflect the variability in shrub species' responses to elevation, as highlighted by Martinez *et al*. (2023).

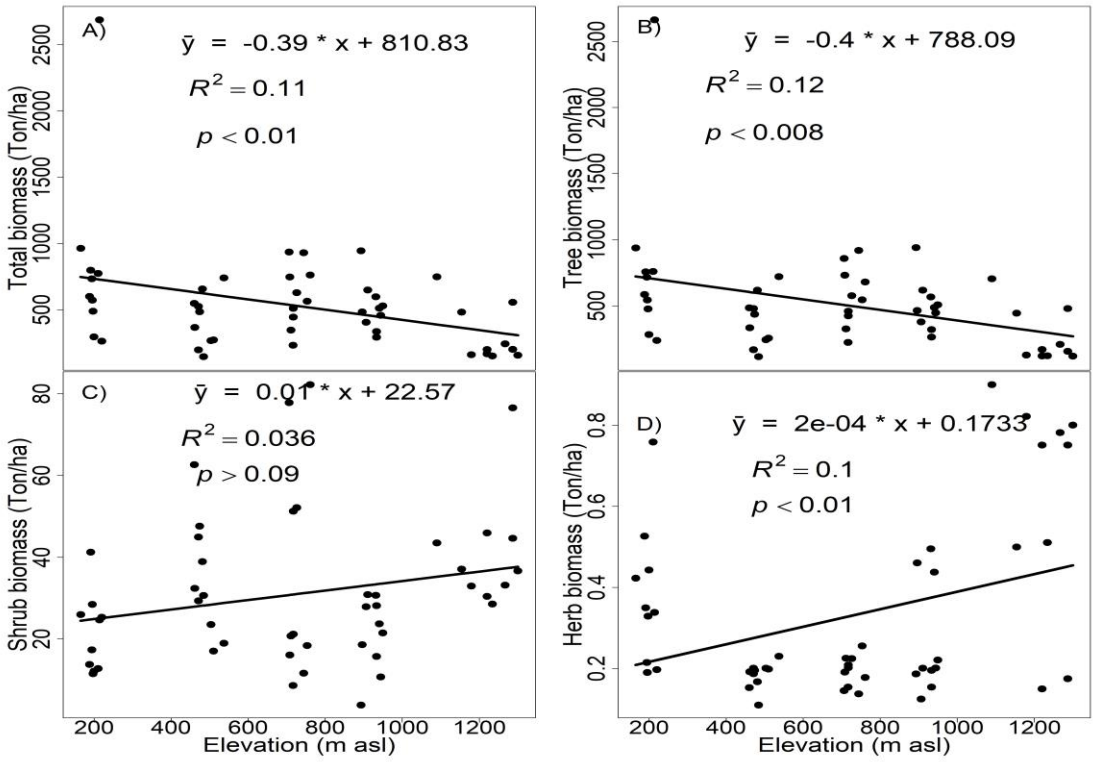


Figure 23: The relationship between biomass and elevation. The fitted line is the linear first order after linear model (*lm*): A) Total biomass, B) Tree biomass C) Shrub biomass, and D) Herb biomass. The equation of the selected model with coefficient of determination (R^2) and their *p*-values are given.

Hence, these results partially supported the hypothesis that plant species biomass decreases with increasing elevation. The significant decline in total biomass and tree biomass with elevation aligns with the hypothesis, reflecting the challenging conditions at higher elevations that restrict biomass accumulation. However, the observed increase in herb biomass with elevation and the non-significant trend for shrub biomass suggest that the relationship between biomass and elevation is more complex than initially proposed. These findings indicate that while some plant types, particularly trees, exhibit a clear decrease in biomass with elevation, others, like herbs, may thrive under higher elevation conditions. Thus, the hypothesis is partially validated, but the variability among plant groups highlights the need for a nuanced understanding of how different plant species respond to elevational gradients."

4.2.3 Relationship between biomass and species richness

Recent studies have provided mixed insights into the relationship between biomass and species richness, reflecting ongoing debates in ecology. The observed positive relationship between shrub and herb biomass with their species richness (**Figure 24 C** and **D**) aligns with findings from several recent studies. For instance, Wright *et al*. (2023) found that higher species richness in understory plants, such as shrubs and herbs, often leads to greater biomass due to niche complementarity and resource partitioning. They argue that species-rich communities are better at exploiting available resources, resulting in higher productivity. Similarly, Zhang *et al*. (2022) highlighted that diverse herbaceous communities tend to exhibit stronger facilitative interactions, enhancing overall biomass.

In contrast, the finding that total and tree biomass showed a declining relationship with richness (**Figure 24 A** and **B**), but not statistically significant, adds to a growing body of literature that questions the universality of the richness-biomass relationship. Huang *et al*. (2021) reported similar trends, suggesting that in some forest ecosystems, increased tree species richness may lead to competition for limited resources, thereby reducing overall biomass. They posited that such competitive dynamics might overshadow the positive effects of diversity on productivity, particularly in resource-limited environments. However, Loreau *et al*. (2022) argued that while such negative or neutral relationships can be observed, they often arise from short-term studies or specific environmental contexts. They emphasize the

importance of long-term and large-scale studies to capture the full complexity of biodiversity-ecosystem function relationships.

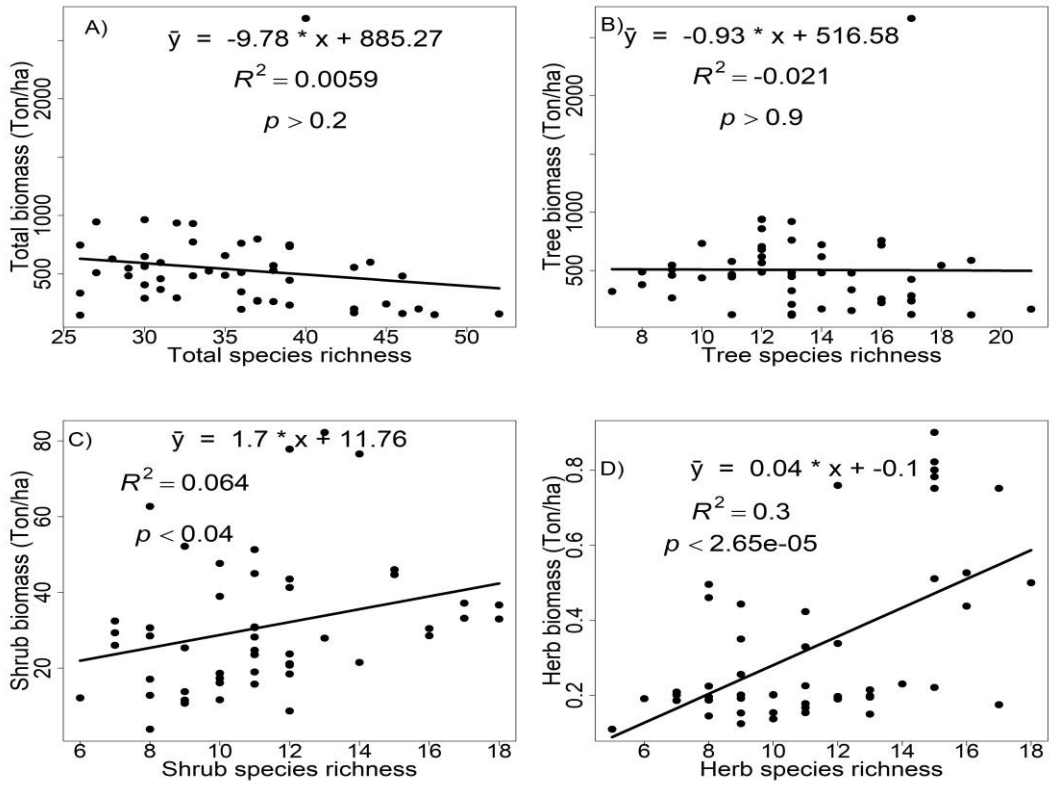


Figure 24: The relationship between biomass and species richness. The fitted line is the linear first order after linear model (*lm*): A) Total biomass, B) Tree biomass C) Shrub biomass, and D) Herb biomass. Regression equation for each linear line, coefficient of determination (R^2) and the probability values (*p*-values) of each model are given.

The lack of statistical significance in the total and tree biomass relationships in this study **(Figure 24 A and B)** may also accordance with Tilman *et al*. (2014), who pointed out that the strength of richness-biomass relationships can be influenced by species composition and environmental variables, which may mask the effects of species richness. They suggest that in some cases, the identity and functional roles of species may be more critical than the number of species present, leading to weak or inconsistent relationships between richness and biomass.

These findings contribute to ongoing debates on how biodiversity influences ecosystem functions. Some authors argue that the relationship is highly context-dependent, varying with factors like the spatial scale, environmental conditions, and the specific plant functional group under consideration. The significant positive

relationship between shrub and herb biomass and richness supports the idea that biodiversity's benefits are most apparent in certain functional groups, a view supported by Cardinale *et al*. (2021), who advocate for more targeted conservation strategies that consider the functional roles of species. However, the uncertain trend observed for total and tree biomass calls for further research to explore the underlying mechanisms and conditions that modulate these relationships.

Hence, the findings of this study present a subtle view of the relationship between plant biomass and species richness. The significant positive relationship between shrub and herb biomass and their species richness supports the hypothesis that increased species richness can enhance biomass production in specific plant functional groups. This result underscores the importance of diverse plant communities in boosting biomass through mechanisms such as niche complement and facilitation. However, the lack of a significant relationship for total and tree biomass challenges the generalization of the hypothesis, suggesting that the influence of species richness on biomass may be influenced by factors such as competition and resource limitation. The observed variations highlight the need for a more exact understanding of how biodiversity impacts biomass production, emphasizing the role of specific plant groups and environmental contexts. Future research should focus on exploring these dynamics further, incorporating a broader range of functional traits and long-term data to refine our understanding of the biodiversity-biomass relationship.

4.2.4 Litter mass and carbon stock

Total litter mass accumulated on the forest floor was highest in Raja-Rani forest (25.7 Mg ha^{-1}) and the lowest in Adheri forest (7.1 Mg ha^{-1}) (**Table 18**). Contribution of leaf litter ranged from 6% to 51%, non-leaf litter ranged from 25% to 86% and partially decayed litter ranged from 8% to 24% to the total litter mass across the forests located at different elevations. The leaf litter mass was highest in Bhaunne forest (7.1 Mg ha^{-1}) and lowest in Sagma forest (1.4 Mg ha^{-1}). Similarly, the value of partially decomposed litter mass was lowest in Adheri forest (1.7 Mg $ha^{-1)}$ and highest in Raja-Rani forest (3.0 Mg ha^{-1}). Surprisingly, non- leaf litter mass was maximum in Sagma forest (21.5 0 Mg ha^{-1}) and it was minimum at Adheri forest (1.8 Mg ha^{-1}).

The carbon stock in litter mass value at the five different forests ranged between 3.66 and 13.37 (Mg C ha^{-1}) and was in the order of Sagma > Raja-Rani >Bhaunne > Murchungi > Adheri (**Table 19**). At Murchungi and Adheri forest highest contribution to the total carbon was seen by leaf litter carbon, while at the Bhaunne, Raja-Rani and Sagma forest maximum contribution of carbon stock was seen from the non-leaf components.

Litters are the important source of aboveground carbon and nutrients to the soil. Litter mass accumulated on the forest floor reflects the balance between rate of litter fall and rate of litter decomposition. Turnover rate of litter layer on the forest floor indicate the percentage replacement of litter mass in each year. Rate of litter fall depends on the type of plant species and their phenologies. In the present study, it did not show a regular trend; with the elevation. It is maximum in Raja-Rani forest and minimum in Adheri forest. Contribution of leaf litter in total litter mass ranged from 6% to 51%, lower in Sagma forest and higher in Adheri and Murchungi forest. At Sagma forest (1200 m) partially decomposed component was minimum while non leaf litter (wood) was maximum. It may happen due to less decomposition rate at high elevation (Garkoti & Singh, 1995).

Litter accumulation in moist forest is mainly influenced by favorable microclimate such as temperature, rainfall and differences in species composition (Yang *et al*., 2004). Hill Sal forest showed lower value of litter mass on the forest floor due to lower litter production as it is located on high elevation. Turnover rate of litter layer on the forest floor indicate the percentage replacement of litter mass in each year. Turnover rate is reported as higher in Tarai Sal forest (lower elevation) due to high temperature and soil moisture and it decreased in Hill Sal forest due to high elevation, lower temperature and low soil moisture (Bhattarai & Mandal, 2013).

Same trend of turnover was reported by (Garkoti & Singh, 1995) in the forests of Central Himalaya. Lugo *et al*. (1978) reported a lower turnover rate (0.34) for sub-tropical dry forest at Puerto Rico, while the turnover rate of three tropical Australian rain forests was as high as 1.4- 2.2 (Spain, 1984).

Table 18: Forest floor litter mass (Mg ha^{-1} ± SE) of forests located at different elevations of Morang district, eastern Nepal (results after Friedman's multiple comparison tests).

	Bhaunne (200 m)		**Raja-Rani (500 m)**		**Murchungi (800 m)**		**Adheri (1000 m)**		**Sagma (1200 m)**	
Litter mass components	Litter mass	% of total	Litter mass	% of total	Litter mass	% of total	Litter mass	% of total	Litter mass	% of total
Leaf	7.1^{a} ± 0.4	40	3.8^{b} ± 0.3	15	5.8^{ab} ± 0.5	51	3.6^{ab} ± 0.3	51	1.4^{c} ± 0.1	6
Non-leaf	8.6^{c} ± 0.5	49	18.9^{a} ± 4.9	73	3.8^{b} ± 1.1	33	1.8^{b} ± 0.2	25	21.5^{a} ± 19.5	86
Partially decomposed	1.9^{ab} ± 0.2	11	3.0^{ab} ± 1.2	12	1.8^{ab} ± 0.2	16	1.7^{ab} ± 0.4	24	2.1^{ab} ± 0.2	8
Total	17.6	100	25.7	100	11.4	100	7.1	100	25	100

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

Table 19: Carbon stock (Mg C ha^{-1}) of forest floor littermass in five forests of Morang district, eastern Nepal

Forest/Component	**Bhaunne (200 m)**	**Raja-Rani (500 m)**	**Murchungi (800 m)**	**Adheri (1000 m)**	**Sagma (1200 m)**
Leaf	3.65	2.05	3.24	1.95	0.77
Non-leaf	4.41	9.77	2.07	0.98	11.88
Partially decomposed	0.56	0.75	0.53	0.73	0.72
Total	8.62	12.57	5.84	3.66	13.37

The variation may be attributed to variation in composition of species, age and climate as these factors influence the litter fall production (Bhattarai & Mandal, 2018; Qiu *et al*., 2023). Density, basal area, age structure, seasons, (Sundarapandian & Swamy, 1999) and elevation (Garkoti & Singh, 1995) all have a significant impact on littermass dynamics in natural forest ecosystems.

4.2.5 Nutrient concentrations and their stock in littermass

4.2.5.1 Nutrient concentration in littermass

N, P, K concentrations in the component of littermass were in the order of Leaf > Partially decomposed > Non-leaf components for all forests. In leaf, N concentration ranged 1.04 to 1.52 %, which was lowest in Murchungi forest and highest in Sagma

forest. While partly decomposed component contained lowest (0.85%) at Murchungi forest and highest N (1.13 %) at Adheri forest.

P concentration was almost similar which ranged from 0.25 to 0.3 mg/100 g in leaf component. In partially decomposed, P concentration ranged between 0.18 and 0.32 mg/100 g, minimum at Adheri forest and the maximum at Bhaunne forest. K concentration in leaf was highest (56. 68 mg /100 gm) at Raja-Rani forest and minimum (37.23 mg/ 100 gm) at Bhaunne forest among the components (**Table 20**).

Table 20: Concentration of nutrients in different components of litter mass in the forests located at different elevations in Morang district, eastern Nepal.

	Leaf			**Non-leaf**			**Partially decomposed**		
Forests	N (%)	P mg/ 100g	K mg/100g	N (%)	P mg / 100g	Kmg/100g	N (%)	P mg / 100g	K mg/100g
Bhaunne (200 m)	1.12	0.3	37.23	0.94	0.21	22.19	1.01	0.32	26.36
Raja-Rani (500 m)	1.13	0.25	56.68	0.92	0.2	28.47	1.09	0.21	24.42
Murchungi (800 m)	1.04	0.27	38.01	0.85	0.22	12.8	0.85	0.2	22.49
Adheri (1000 m)	1.2	0.28	39.5	0.95	0.25	13.98	1.13	0.18	32.38
Sagma (1200 m)	1.52	0.29	53.2	0.65	0.24	11.3	0.9	0.25	16.2

4.2.5.2 Nutrient stocks in litter mass

Amount of nutrient stocks in litter mass were distinctly different in different components of litter mass (**Table 24**). In leaf litter, amount of N (79.19 Kg $ha^{-1)}$, P (0.02 Kg ha^{-1}) and K (2.63 Kg ha^{-1}) were highest in Bhaunne forest than other four forests. The lowest amount of N (21.46 Kg ha^{-1}), P (0.004 Kg ha^{-1}), and K (0.75 Kg ha^{-1}) of leaf litter were at Sagma. Leaf nitrogen amount was significant ($p < 0.05$) between Bhaunne and Sagma forest, Raja-Rani and Sagma forest, Murchungi and Sagma, and Adheri and Sagma forest. Similarly, P stock in leaf was significant between Bhaunne and Raja-Rani forest, Adheri and Sagma forest, Raja -Rani and Sagma forest and so on. While leaf K was significant between Bhaunne and Sagma

forest, Raja-Rani and Sagma forest, Murchungi and Sagma forest, and Adheri and Sagma forest.

In the non- leaf litter maximum of N (173.75 Kg ha^{-1}) and K (5.38 Kg ha^{-1}) were at Raja-Rani forest, while amount of P was maximum at Sagma forest. Non- leaf litter had the lowest amount of N (17.11 Kg ha^{-1}), P (0.005 Kg $ha^{-1)}$, and K (0.25 Kg $ha^{-1)}$ at Adheri forest. Non-leaf littermass N amount was significant between Bhaunne and Raja-Rani, and Bhaunne and Adheri forest. Likewise, K was significant between Bhaunne and Raja-Rani forest and P was significant between Bhaunne and Raja-Rani forest, Raja-Rani and Murchungi forest, Bhaunne and Adheri forest and Murchungi and Adheri forest.

Additionally, partially decomposed litter accounted highest amount of both N (32.63 Kg $ha^{-1)}$, and K (0.73 Kg ha^{-1}) at Raja-Rani forest, while highest amount of P (0.01 Kg ha^{-1}) at both Bhaunne and Raja-Rani forests. The lowest amount of nutrients in partially decomposed litter was occurred as N (15.46 Kg ha^{-1}), P (0.003 Kg ha^{-1}), and K (0.34 Kg ha^{-1}) at Murchungi, Adheri and Sagma forest respectively. Nitrogen amounts in partially decamped littermass was not significant ($p > 0.05$) among the forests, where as K was significant ($p < 0.05$) between Murchungi and Adheri forest and Adheri and Sagma forest, whereas P was insignificant ($p > 0.05$) between the different forests (**Table 21**).

Table 21: Nutrient stocks (Kg ha^{-1} ±SE) in different components of litter mass of forests located along different elevations, east Nepal (results after Friedman's multiple comparison tests).

Site	Leaf			Non-leaf(wood)			Partially decomposed		
	N	P	K	N	P	K	N	P	K
Bhaunne (200 m)	79.19^{a}	0.02^{b}	2.63^{a}	80.52^{b}	0.02^{a}	1.90^{ab}	19.08^{a}	0.01^{a}	0.50^{ab}
	± 4.21	±0.001	±0.14	±5.15	±0.001	±0.12	±2.45	±0.001	±0.06
Raja-Rani (500 m)	42.93^{b}	0.01^{a}	2.15^{a}	173.75^{a}	0.04^{a}	5.38^{a}	32.63^{a}	0.01^{a}	0.73^{a}
	±3.78	±0.001	±0.19	±45.11	±0.01	±1.40	±13.38	±0.003	±0.30
Murchungi (800 m)	60.01^{a}	0.02^{b}	2.19^{a}	31.93^{c}	0.01^{a}	0.48^{b}	15.46^{a}	0.004^{a}	0.41^{b}
	±4.72	±0.001	±0.17	±9.52	±0.002	±0.14	±2.01	±0.0005	±0.05
Adheri (1000 m)	43.63^{a}	0.01^{b}	1.44^{a}	17.11^{c}	0.005^{a}	0.25^{ab}	18.91^{a}	0.003^{a}	0.54^{ab}
	±3.59	±0.001	±0.12	±2.30	±0.001	±0.03	±4.46	±0.0007	±0.13
Sagma (1200 m)	21.46^{c}	0.004^{c}	0.75^{b}	139.87^{a}	0.05^{a}	2.43^{b}	19.13^{a}	0.005^{a}	0.34^{b}
	±1.99	±0.0004	±0.07	±126.52	±0.05	±2.20	±1.54	±0.0004	±0.03
Total	247.22	0.064	9.16	443.18	0.125	10.44	105.21	0.032	2.52

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

There are differences in the amount of nutrient stocks in the littermass along varied elevations. This is basically explained by the amount of litter mass rather than the concentration of nutrients. In the case of nitrogen concentration, it is higher in leaf litter in all sites but the amount of nitrogen stocks is higher in non-leaf (wood) component except two sites Murchungi forest and Adheri forest.

However, nitrogen stocks on the leaf litter were maximum in Bhaunne forest and minimum in Sagma forest. This trend is also in accordance with difference in leaf littermass. With few exceptions same pattern is found in the case non-leaf (wood) and partially decomposed component of littermass. As there is minimum littermass of partially decomposed component, obviously the nutrient stocks are also minimum in this component. From the forest functioning point of view, the contribution of leaf litter is considerably higher as the nutrient stocks are more which become available to the forest floor after decomposition. According to Vitousek (1994), the altitudinal difference affects the microclimate and the activities of microorganisms that slow down or speed up the turnover of leaf litter.

A fundamental aspect of the functioning of terrestrial ecosystems is the determination of the dynamics of litter and available litter nutrient stocks over time (Martius *et al*., 2004). Both the biomass of the litter and its chemical content are required to determine the annual return of elements and organic matter to the soil (Hansen *et al*., 2009). Nutrient stock in the forest floor depends upon quantity of litter mass. Moreover, it may also depend upon nutrient concentration of litter which depend upon sites and characteristics of the species involved (Yang *et al*., 2005). The nutrient contribution to the forest floor through the litter mass in the present study was comparable to that reported by Garkoti & Singh (1995) in forest of Central Himalaya, India and Mandal (1999) in Plateau Sal forest, Nepal.

The source of nutrients on the forest floor is due to the decomposition of littermass. The turnover rate for different litter nutrients (N, P and K) on the forest floor was higher in Tarai Sal forest than Hill Sal forest as reported by Bhattarai & Mandal, (2016). The decomposition of litter, a critical link in the movement of matter and energy throughout ecosystems, regulates the balance of nutrients and affects the physical and chemical characteristics of soil, soil fertility, and plant productivity

(Austin & Vitousek, 2000). Rapid nutrient (N, P, K) turnover on the forest floor in tropical forests resulted to a reduction in the amount of nutrients in the littermass.

4.2.6 Fine root biomass (FRB) and carbon stock

Among all the five forests, the total fine root biomass combining both diameter size classes (<2 and 2-5mm) and depths (0-15 cm and 15-30 cm) were maximum (16.00 Mg $ha^{-1)}$ in Murchungi forest and minimum (7.14 Mg ha^{-1}) were at Bhaunne forest. Fineroot biomass was found to be higher in the upper 0-15 cm soil depth than the lower 15-30 cm soil depth. In both the soil layer 0-15 cm and 15-30 cm FRB were high in Murchungi forest comprised 9.63 Mg $ha^{-1}$and 6.37 Mg ha^{-1} respectively. Considering the diameter size class fineroot biomass value was always higher in <2 mm diameter than 2-5 mm size in both upper and lower depth due to high turnover rate as compared to those with 2-5 mm diameter (Gautam & Mandal, 2016). As per the trend in fineroot biomass, the value of carbon stock in fine roots was also higher (7.00 Mg C ha^{-1}) in Murchungi forest (800 m) and lower value (2.9 Mg C ha^{-1}) in Bhaunne forest (200 m) (**Table 22**).

Table 22: Fine root biomass (Mg ha^{-1} ± SE) of different size classes in two soil depths in five forests of Morang district, eastern Nepal (results after Friedman's multiple comparison tests).

Soil depth (cm)	Fine root class (mm)	Bhaunne (200 m)	Raja-Rani (500 m)	Murchungi (800 m)	Adheri (1000 m)	Sagma (1200 m)
0-15						
	<2mm	$3.46^{a} \pm 0.3$	$4.38^{a} \pm 0.4$	$6.55^{a} \pm 1.3$	$3.42^{a} \pm 0.4$	$4.54^{a} \pm 0.8$
	2-5mm	$1.70^{a} \pm 0.6$	$2.98^{a} \pm 0.8$	$3.08^{a} \pm 0.7$	$2.29^{a} \pm 0.4$	$1.54^{a} \pm 0.4$
	Total	$5.16^{a} \pm 0.8$	$7.36^{a} \pm 1.0$	$9.63^{a} \pm 1.9$	$5.71^{a} \pm 0.6$	$6.08^{a} \pm 1.2$
15-30	**<2mm**	$1.47^{b} \pm 0.3$	$3.08^{ab} \pm 0.4$	$4.01^{a} \pm 0.5$	$2.48^{ab} \pm 0.3$	$2.57^{ab} \pm 0.3$
	2-5mm	$0.51^{b} \pm 0.1$	$2.29^{a} \pm 0.4$	$2.36^{a} \pm 0.6$	$1.35^{ab} \pm 0.2$	$1.05^{ab} \pm 0.2$
	Total	$1.98^{b} \pm 0.3$	$5.37^{a} \pm 0.8$	$6.37^{a} \pm 1.0$	$3.83^{ab} \pm 0.3$	$3.62^{ab} \pm 0.5$
0-30	**Total**	$7.14^{a} \pm 0.8$	$12.73^{a} \pm 1.4$	$16.00^{a} \pm 2.7$	$9.54^{a} \pm 0.8$	$9.70^{a} \pm 1.4$

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

Though, along with the elevation it did not show a regular trend. Higher level of fine root biomass in Murchungi may be influenced by the type of plant species in the composition (Pandey *et al*., 2023; Raich *et al*., 2009). Swift *et al*. (1979) observed that a decrease in the rate of decomposition led to a fall in the biomass of fine roots, which

generally happens with high elevations. Low value of fine root biomass in Bhaunne forest may be due to fast turnover rate.

Due to availability of moisture and nutrients, fineroot biomass was found to be higher in 0-15 cm than the 15-30 cm soil depth. Accumulation soil organic matter on the upper soil surface causes high biomass on it. Chuang *et al*. (2012) also reported high fineroot biomass in upper soil depth. In support of current study, Bhattarai & Mandal (2013) showed that in the Kiteni sal forest, Ilam, fine root biomass was higher (3.21 t ha^{-1}) in 0-15 cm soil depth than 15-30 cm depth (1.20 t ha^{-1}).

The fine root biomass shared 1-2 % carbon to total stand biomass carbon among the forests. Comparable to the fact that the biomass carbon stored in fine roots, only contributes 2% of the total carbon stocks in terrestrial ecosystems at the global scale (Vogt *et al.,* 1996). Fine root biomass supplied the least amount of carbon to the total carbon when compared to other carbon pools. The distribution of fine roots was greatly impacted by the physical and chemical properties of the soil (Pandey *et al*., 2023). Fine roots biomass showed a unimodal pattern in the present study which is in accordance with the findings reported by Arunachalam *et al*. (1996).

4.2.7 Nutrient concentrations and their stocks in fine root

4.2.7.1 Nutrient concentrations in fine roots

Fine roots are the active absorptive parts for nutrient uptake from the soil. The nutrients concentrations in fine root are summarized in **Table 23**. Generally, N and P concentrations were higher in <2 mm size which decreased with increase in root diameter in 2-5 mm diameter size at all the five forests. Potassium (K) concentration revealed greater in amount 2-5 mm than the < 2 mm diameter of fine roots at all the five forests.

Table 23: Nutrient concentrations in fine root of different diameter size classes in five forest located at different elevations of Morang district, eastern Nepal**.**

Forests	Fineroots size	N %	P (mg / 100gm)	K (mg/100gm)
Bhaunne (200 m)	<2mm	1.23	0.29	12.69
	2-5mm	0.88	0.27	63.42
Raja-Rani (500 m)	<2mm	1.01	0.35	35.66
	2-5mm	1.11	0.3	39.45
Murchungi (800 m)	<2mm	1.2	0.19	30.93
	2-5mm	0.82	0.23	41
Adheri (1000 m)	<2mm	1.01	0.18	31.39
	2-5mm	0.99	0.17	44.36
Sagma (1200 m)	<2mm	0.92	0.28	33.77
	2-5mm	0.85	0.28	40.89

4.2.7.2 Nutrient stocks in fine roots

As per the content of biomass in fine root, nutrient stocks in fine roots were higher in fine roots with <2 mm diameter at upper (0-15 cm) soil depth and these decreased with diameter size (2-5mm) and of soil depth (**Table 24**). Considering both depths the fine root of <2 mm diameter contained maximum amount of N stock (106.96 Kg ha^{-1}) at Murchungi forest and the lowest amount of N stock were (48.27 Kg ha^{-1}) at Adheri forest. In case of 2-5 mm diameter fine root, maximum N stock (58.54 Kg ha^{-1}) was obtained at Raja-Rani forest. Total fine roots considering both size and both depths had maximum amount of N value (163.25 Kg ha^{-1}) at Murchungi forest and it was the lowest at Bhaunne forest (68.24 Kg ha^{-1}).

Considering P stock (Kg ha^{-1}) of <2 mm diameter fine root at both depths, it was maximum (0.03 Kg ha^{-1}) at Raja-Rani and minimum (0.014 Kg ha^{-1}) at both Bhaunne and Adheri. In case of 2-5 mm diameter fine roots, P stock was highest (0.02 Kg ha^{-1}) for both Raja-Rani and Murchungi forest, while it was lowest (0.007 Kg ha^{-1}) at Sagma forest. The P stock value in total fine root at 0-30 cm soil depth was maximum (0.04 Kg ha^{-1}) at Raja-Rani forest and P stocks was minimum (0.02 Kg ha^{-1}) at both Bhaunne and Adheri forest.

Considering of the both depth, fine root of <2 mm diameter size, highest value of K stock was obtained as 3.27 Kg ha^{-1} at Murchungi forest and the lowest value of it was 0.63 Kg ha^{-1} at Bhaunne forest. In 2-5 mm diameter sized fine roots the maximum amount of K was 2.23 Kg ha^{-1} in Murchungi forest and the minimum amount of K was 1.06 Kg ha^{-1} at Sagma forest. The total amount of K stocks was high at Murchungi forest (5.5 Kg ha^{-1}) and lowest value of K stock was 2.03 Kg ha^{-1} at Bhaunne forest among the forests at 0-30 cm soil depth.

Friedman's test on amount of N, P, K of fine root biomass (<2mm and 2-5mm diameter sized, at both soil depths) was shown in details at **Table 23**. whereas, amount of K of fine root biomass (<2mm) at 0-15cm soil depth was significantly different between Bhaunne and Raja-Rani forest, Raja-Rani and Sagma forest and Raja-Rani and Adheri forest. Whereas, amount of K of fine root biomass of <2mm diameter size at 15-30cm soil depth was significantly ($p < 0.05$) between Bhaunne and Raja-Rani forest, Raja-Rani and Sagma forest and Raja-Rani and Murchungi forest,

The levels of nutrients in each component of plant vary significantly between forests. The effects of nutrient concentrations, soil depths, fine root diameter and seasons played a supportive role in the fluctuations in nutrient stocks, but the principal cause is the differences in biomass (Gautam & Mandal, 2016; Bhattarai *et al*., 2020).

The active absorptive components for nitrogen uptake from the soil are the fine roots. Concentrations of N and P declined as root diameter increased, fine roots of <2 mm diameter had maximum concentration compared to 2-5 mm diameter in all five forests. Higher nutrient stocks in fine root are due to high biomass value. As per the fine root biomass values, the amount of N, P, and K stocks were also higher in <2 mm diameter than 2-5 mm diameter. Thus, contribution of fine root having <2 mm diameter is more pronounced for forest ecosystem functioning. N, P, K stocks did not show regular trend along the increasing elevation, while it reduced as lower soil depth.

Table 24: Nutrients stocks (N, P, K Kg ha^{-1} ±SE) in fine roots of different size classes at 0-15 cm and 15-30 cm soil depths in five forests of Morang districts, eastern Nepal, results after Friedman's multiple comparison test.

	N(Kg ha^{-1})				P (Kg ha^{-1})				K (Kg ha^{-1})			
Root size class	**<2mm**		**2-5mm**		**<2mm**		**2-5mm**		**<2mm**		**2-5mm**	
Forests/Soil depth(cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
Bhaunne	42.52^{a}	6.29^{b}	14.93^{b}	4.50^{a}	0.01^{ab}	0.004^{ab}	0.005^{ab}	0.001^{b}	0.44^{c}	0.19^{a}	1.08^{ab}	0.32^{b}
(200 m)	±3.99	±1.40	±4.97	±1.00	±0.0009	±0.001	±0.002	±0.0003	±0.04	±0.03	±0.36	±0.07
Raja-Rani	44.24^{a}	23.21^{a}	33.03^{a}	25.51^{b}	0.02^{a}	0.01^{a}	0.01^{ab}	0.01^{a}	1.56^{b}	1.10^{ab}	1.17^{ab}	0.91^{a}
(500 m)	±3.79	±4.45	±8.75	±4.89	±0.001	±0.002	±0.002	±0.001	±0.13	±0.15	±0.31	±0.17
Murchungi	78.59^{a}	28.37^{a}	36.91^{a}	19.38^{ab}	0.01^{ab}	0.01^{ab}	0.01^{ab}	0.01^{ab}	2.03^{ab}	1.24^{b}	1.26^{ab}	0.97^{ab}
(800 m)	±15.57	±6.68	±8.36	±4.57	±0.002	±0.001	±0.002	±0.001	±0.40	±0.16	±0.29	±0.23
Adheri	34.53^{a}	13.74^{ab}	22.71^{ab}	13.46^{ab}	0.01^{b}	0.004^{b}	0.004^{ab}	0.002^{ab}	1.52^{b}	0.78^{a}	1.02^{ab}	0.60ab
(1000 m)	±3.99	±2.22	±3.91	±2.18	±0.0007	±0.0005	±0.0007	±0.0004	±0.18	±0.09	±0.18	±0.10
Sagma	41.78^{a}	9.65^{b}	13.12^{b}	8.92^{a}	0.01^{ab}	0.01^{ab}	0.004^{ab}	0.003^{b}	1.86^{b}	0.87^{a}	0.63^{ab}	0.43^{ab}
(1200 m)	±7.59	±1.54	±3.37	±1.42	±0.002	±0.001	±0.001	±0.0005	±0.34	±0.12	0.16	±0.07

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

This is because variation in fine root biomass also did not show a regular trend along the elevation gradient. Fine root biomass value is maximum at Murchungi having 800 m elevation. At this site, the levels of soil organic carbon, total nitrogen and phosphorus are minimum. so to absorb the maximum nutrients the fine roots are developed in greater mass. So, the nutrient stocks are also maximum at Murchungi. Amount of fine root is affected by stand characteristics, tree density, basal area and biomass (Uselman *et al*., 2007; Pandey *et al*., 2023).

On the other hand, considering both diameter size (<2 mm and 2-5 mm) of fine root, the value of nutrient stocks is minimum at low elevation (200 m) Bhaunne forest due to minimum biomass value. At this site soil moisture, WHC, organic carbon and total nitrogen are maximum which may help to high turnover rate of fine root (Swift *et al*., 1979).

Considering P stocks (kg ha^{-1}) of <2 mm diameter fine root, it was maximum (0.03 Kg ha^{-1}) at Raja-Rani forest and minimum at both Bhaunne and Adheri forest. The maximum P concentrations and stocks may be due to sandy soils which boost up fine root (Mosquera & Hurtado, 2022).

4.2.8 Soil characteristics

4.2.8.1 Soil physio-chemical characteristics

Soil texture ranged from sandy loam to loamy sand in upper (0-15 cm) and lower (15-30 cm) depth. The texture of Adheri forest was loamy sand in both soil depths and it was sandy loam in Sagma forest at both soil depths. In Adheri forest sand content was maximum, 83.35 % and 75.83 % in upper and lower depth respectively. It was minimum, 50.70 % and 50.80 % in Raja-Rani forest at 0-15 cm and 15-30 cm soil depth respectively (**Table 25**). In the soil depth, 0-15 cm and 15-30 cm, silt contents were highest in Raja-Rani forest, while lowest in Adheri forest. Soil texture plays an important role in the vegetation development and nutrient cycling because of its main role in supply of air, water and nutrients required for root development.

Moisture content in the upper layer (0-15 cm depth) ranged between 8.48 % and 21.29%, minimum in Adheri forest (1000 m) and maximum in Bhaunne forest (200 m). Generally, the soil moisture in the lower soil depth (15-30 cm) decreased. Soil

moisture between Bhaunne and Sagma forest significantly ($p < 0.05$) different. In both 0-15 cm and 15-30 cm soil depth, water holding capacity (WHC) was minimum 70.74% and 68.21 % respectively in Raja-Rani forest (500 m), while it was maximum 97.48% and 94.37% respectively in Bhaunne forest (200 m). Water holding capacity at 0-15 cm soil depth was significantly different between Bhaunne and Raja-Rani forest, Bhaunne and Murchungi forest, whereas at 15-30 cm soil depth, water holding capacity (WHC) was significantly different ($p > 0.05$) between the forests Bhaunne and Raja-Rani. Bulk Density value in upper soil layer ranged between 0.94 and 1.48 g cm^{-3}, the minimum in Bhaunne forest and maximum in Murchungi forest stand. Bulk density was insignificant ($p > 0.05$) among the forests at upper layer (0-15 cm). Conversely, the porosity was maximum in Bhaunne forest (200 m) and minimum in Murchungi forest stand (800 m).

The soil in all forests was acidic, soil pH ranged from 5.06 to 5.68 in upper oil depth and slightly higher as 5.14 to 5.73 in lower soil depth. Soil pH affects a wide range of soil chemical and biological properties (Brady & Weil, 2013). The pH value in the present study was lower than the values (5.90-6.42) reported by Sigdel (1994) for Royal Chitwan National Park. Acidification of forest soil may result through the microbial degradation of soil organic matter and the creation of weak organic acid by dissolving carbon dioxide in soil water. The upper layer of soil revealed a more acidic nature, due to higher concentration of partially decomposed organic matter on the forest floor, which caused the formation of organic acids and leaching of alkaline cations (such as Ca, Na, K, Mg) from upper to lower layer (Gautam & Mandal, 2013).

Soil organic carbon and total nitrogen were maximum in the Bhaunne forest (200 m), located at lowest elevation which decreased as the elevation increase as per the hypothesis and again slightly increase in Adheri and Sagma forest (high altitude forests) against the hypothesis.

Soil organic carbon (SOC) in the upper soil depth (0-15 cm) ranged between 1.26% and 3.04% minimum in Murchungi forest and maximum in Bhaunne forest indicating fertile soil (**Table 26**). Soil organic carbon decreased in lower soil depth (15-30 cm) in all forest stands, ranged from 0.95 %-2.29%. Soil organic carbon of upper depth was significantly ($p < 0.05$) different between Bhaunne and Murchungi forest, Raja-Rani and Sagma forest, Raja-Rani and Bhaunne forest and at lower depth SOC was

significantly different between Murchungi and Bhaunne forest, significantly (p < 0.05) different between Raja-Rani and Bhaunne forest, Bhaunne and Adheri, Murchungi and Bhaunne, and Bhaunne and Sagma forest. The major source of terrestrial carbon is soil organic carbon, which raises ion exchange capacity, WHC, and nutrient availability. With increasing soil depth in studied forests, the chemical properties of the soil varied noticeably. In the present study, the mean soil organic carbon, total nitrogen, and available potassium decreased with the increase in soil depth. At 0-15 cm soil depth, phosphorus was significantly different between Bhaunne and Raja-Rani forest, Murchungi and Adheri forest, Adheri and Sagma forest, Bhaunne and Sagma forest. While, at depth of 15-30 cm, phosphorus was significantly different (p < 0.05) between Bhaunne and Raja-Rani forest, Bhaunne and Murchungi forest, Bhaunne and Adheri and Adheri and Sagma forest. Similarly, potassium was significantly different (p < 0.05) between Bhaunne and Raja-Rani forest, Raja-Rani and Murchungi forest, Murchungi and Adheri etc.

Similarly, N, P and K were also maximum in 0-15 soil depth: 0.26%, 291.17 Kg ha^{-1} and 397.10 Kg ha^{-1} respectively in Bhaunne forest. On the other hand, in the same soil depth minimum value of N (0.12 %) was found in both Raja-Rani and Murchungi forest. Concentration of P was minimum (11.66 Kg ha^{-1}) in Murchungi forest. Concentration of K was exceptionally lower at Raja-Rani forest. Concentration of N and K decreased while P showed increasing trend at lower depth. High N, P, K might be due to fertile soil and high fine root in lower tropical forest (Wright *et al*., 2011). Total N and total K decreased with increasing soil depth in all the five forest stands. Similar results were observed by Barbhuiya *et al*. (2008) in tropical rainforest of Assam, India. The higher total N in Bhaunne forest may be due to the presence of leguminous plant species that fix atmospheric nitrogen. Further, their N rich leaf litter and dead fine roots are also the source of N in the soil. Total Phosphorus value of the forest stands increased with increasing soil depths that may be due to its sedimentary source.

SOC stock varied forest wise, which ranged from 13.99- 53.18 Mg C ha^{-1} at 0-15 cm soil depths, minimum in Sagma forest and maximum value in Bhaunne forest while the value ranged from 20.91 to 39.30 Mg C ha^{-1} at 15-30 cm soil depth, with maximum value in Bhaunne and minimum value in Murchungi forest (**Table 26 & 27**). In the present study, the mean soil organic carbon, total nitrogen, and available

potassium decreased with the increase in soil depth. Similar decreasing trend of soil organic carbon with increase in depth has been reported in a number of literatures (Jobbagy & Jackson, 2000; Dorji *et al*., 2014; Vashum *et al*., 2016). Yang *et al*. (2010) reported that both soil organic carbon and total nitrogen decreased with increase in depth, however the C: N ratio varied with elevation. Gautam & Mandal (2013) also observed the decreasing trend in soil organic carbon and total nitrogen with the increase soil depth in the tropical moist forest of Sunsari, Nepal.

Table 25: Physical characteristics of soil (0-15 and 15-30 cm depth) in five forests located at different elevations of Morang district, eastern Nepal. Values are mean ± SE (n=50 for each depth), results after Friedman's multiple comparison tests.

Soil Characteristics	Forest stands and Soil depth (cm)									
	Bhaunne (200 m)		Raja-Rani (500 m)		Murchungi (800 m)		Adheri (1000 m)		Sagma (1200 m)	
	0-15	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
Soil texture	Sandy loam	Loamy sand	Loam	Sandy loam	Loamy sand	Loamy Sand	Loamy sand	Loamy sand	Sandy loam	Sandy loam
Sand (%)	66.30^{a} ±2.47	75.30^{a} ±2.17	50.70^{c} ±2.04	50.80^{b} ±2.44	62.55^{a} ± 3.09	59.35^{ab} ± 3.84	83.35^{b} ±1.08	75.83^{a} ±1.05	64.77^{a} ± 1.20	63.55^{ab} ± 1.41
Silt (%)	28.60^{a} ±2.37	21.40^{b} ±2.13	36.10^{c} ±1.58	36.70^{a} ±1.78	28.23^{a} ± 2.18	28.32^{a} ± 2.44	13.10^{b} ±1.16	19.90^{b} ±0.92	25.38^{a} ± 1.08	26.66 ^{a} ± 1.21
Clay (%)	5.10^{b} ±0.50	3.30^{b} ±0.31	13.10^{a} ±1.24	12.00^{a} ±1.41	9.71^{a} ± 1.01	11.98^{a} ± 1.49	3.87^{b} ±0.32	4.67^{b} ±0.42	10.04^{a} ± 0.67	11.31^{a} ± 0.52
Moisture (%)	21.29^{a} ±1.78	18.88^{a} ±1.85	13.62^{b} ±0.54	12.52^{ab} ±0.62	10.02^{ab} ± 1.39	10.68^{ab} ± 1.22	8.48^{a} ±0.6	10.74^{ab} ±1.26	15.84^{b} ± 0.53	16.26^{ab} ± 0.29
Water holding capacity (%)	97.48^{a} ±9.42	94.37^{a} ±11.29	70.74^{b} ±3.78	68.21^{b} ±5.08	72.84^{b} ± 4.52	81.28^{ab} ± 7.63	80.88^{ab} ±1.66	86.29^{ab} ±8.07	90.09^{a} ± 10.02	86.71^{ab} ± 7.94
Bulk Density g cm^{-3}	0.94^{ab} ±0.02	0.84^{ab} ±0.09	1.14^{a} ±0.08	1.19^{ab} ±0.08	1.48^{a} ± 0.03	1.46^{a} ± 0.04	1.16^{a} ±0.07	1.14^{a} ±0.02	0.98^{ab} ± 0.02	1.06^{ab} ± 0.01
Porosity (%)	64.71^{a} ±0.77	64.35^{a} ± 0.46	56.92^{ab} ±3.16	55.01^{ab} ±2.89	44.34^{b} ± 1.17	44.86^{b} ± 1.49	55.54^{ab} ±2.46	55.96^{ab} ±0.80	62.93^{a} ± 0.71	59.96^{a} ± 0.52

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

Table 26: Chemical characteristics of soil (0-15 and 15-30 cm depth) in five forests located at different elevation of Morang district, eastern Nepal. Values are mean ± SE (n= 50 for each depth) results after Friedman's multiple comparison tests.

Soil Characteristics	Forest stands, elevations (m) and Soil depth (cm)									
	Bhaunne (200 m)		Raja-Rani (500 m)		Murchungi (800 m)		Adheri (1000 m)		Sagma (1200 m)	
	0-15	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
pH	5.68^{a} ±0.05	5.73^{a} ±0.06	5.58^{a} ±0.1	5.40^{a} ±0.08	5.31^{a} ± 0.07	5.42^{a} ± 0.09	5.44^{a} ±0.08	5.58^{a} ±0.13	5.06^{a} ± 0.07	5.14^{a} ±0.06
Organic carbon (%)	3.04^{a} ± 0.13	2.29^{a} ± 0.08	1.31^{b} ±0.13	1.24^{ab} ±0.13	1.26^{b} ± 0.06	0.95^{b} ± 0.07	2.28^{ab} ± 0.14	1.93^{ab} ± 0.15	2.48^{a} ± 0.2	2.14^{ab} ± 0.24
Total Nitrogen (%)	0.26^{ab} ±0.01	0.21^{ab} ±0.01	0.12^{ab} ±0.01	0.11^{ab} ± 0.01	0.12^{ab} ± 0.01	0.09^{ab} ± 0.01	0.21^{b} ±0.01	0.17^{ab} ±0.01	0.21^{ab} ± 0.02	0.21^{ab} ± 0.02
Phosphorous (kg ha^{-1})	291.17^{a} ±67.34	302.74^{a} ±76.35	17.99^{b} ±1.58	20.08^{b} ±2.32	11.66^{b} ± 1.31	11.01^{b} ± 0.87	41.79^{c} ±10.77	57.5^{c} ±25.79	12.3^{b} ± 0.37	12.88^{b} ± 0.40
Potassium (kg ha^{-1})	397.10^{a} ±44.10	357.50^{a} ±39.48	17.00^{c} ±5.50	16.90^{c} ±5.08	246.36^{b} ± 21.62	222.23^{b} ± 18.13	374.85^{a} ± 27.55	321.26^{a} ±49.20	255.95^{b} ± 30.2	252.28^{b} ± 41.84
SOC Stock (Mg ha^{-1})	53.18^{a} ±4.11	39.30^{a} ±1.55	21.82^{b} ±2.28	22.37^{b} ±2.94	27.74^{b} ±1.17	20.91^{b} ±1.69	31.93^{b} ±1.95	25.13^{b} ±3.41	13.99^{b} ±2.54	33.92^{b} ±3.62
N Stock (Mg ha^{-1})	4.51^{a} ±0.38	3.59^{a} ±0.28	1.93^{b} ±0.21	1.89^{b} ±0.26	2.61^{ab} ±0.17	1.91^{b} ±0.18	2.88^{ab} ±0.17	2.14^{b} ±0.29	3.10^{ab} ±0.36	3.35^{a} ±0.23
C:N Ratio	11.69^{a} ± 0.21	10.90^{a} ±0.46	10.92^{a} ± 0.16	11.27^{a} ± 0.30	10.50^{a} ± 0.5	10.55^{a} ± 0.32	10.86^{a} ± 0.33	11.35^{a} ± 0.27	11.81^{a} ± 2.54	10.19^{a} ± 0.74

Where, if letters in the superscript of two different forests after multiplying each other results different that represents statistically significant ($p < 0.05$) and if letters are similar that represents statistically non-significant ($p > 0.05$).

4.2.8.2 Soil organic carbon stock

Highest amount of soil organic carbon (SOC) stock was found in Bhaunne forest (92.47 Mg C ha^{-1}) followed by Sagma forest (70. 68 Mg C ha^{-1}) up to 0-30 cm soil depth. The SOC stock at 0-15 cm soil depth was also highest in Bhaunne forest (53.18 Mg C ha^{-1}), while lowest in Raja-Rani forest (21.82 Mg C ha^{-1}). Similarly, SOC stock at 15-30 cm depth of soil was also maximum (39.30 Mg C ha^{-1}) at Bhaunne forest but minimum (20.91 Mg C ha^{-1}) at Murchungi forest (**Table 27**).

Table 27: Soil organic carbon stock (Mg C ha^{-1}) in 0-15 cm and 15-30 cm soil depth in five forests located at different elevations of Morang district, eastern Nepal.

	Forests stands				
Soil depth(cm)	**Bhaunne (200 m)**	**Raja-Rani (500 m)**	**Murchungi (800 m)**	**Adheri (1000 m)**	**Sagma (1200 m)**
0-15	53.18±4.11	21.82±2.28	27.74±1.17	31.93±1.95	36.75±10.96
15-30	39.30±1.55	22.37±2.94	20.91±1.69	25.13±3.41	33.92±3.62
Total	92.47	44.19	48.65	57.05	70.68

Stock of soil organic carbon did not show a regular trend along the changing elevation. The carbon stock in all forests decreased in lower depth (15-30 cm). According to Jobbagy & Jackson (2000), a favorable topsoil environment increases the concentration of SOC, while a decline in biological activity with increasing soil depth may be responsible for a decrease in the SOC stock. Additionally, the majority of the fine root tips are found in the upper soil layer, which also helps to produce nutrient-rich soil (Sheikh *et al.*, 2020).

Variation in carbon stock across the elevational gradient may be due to variation in plant diversity and basal area. According to Sevgi & Tecimen (2008), the loss in vegetation with elevation leads to less litter accumulation, which in turn results in insufficient inputs for the storage of organic carbon in soils. As soil depth increased, SOC drastically declined. This is consistent with the findings of the Zhang *et al*. (2013), Dorji *et al*. (2014), Jobbágy & Jackson (2000) and Wang *et al.* (2016). The decrease in soil carbon is due to an increase in sand percentage in the soil which limits the soil organic matter decomposition rate (Bosatta & Ågren, 1997). Soil carbon showed significant positive associations with soil moisture, bulk density and soil pH, as also reported by Saimun *et al*. (2021).

Relation of soil organic carbon and total nitrogen with elevation

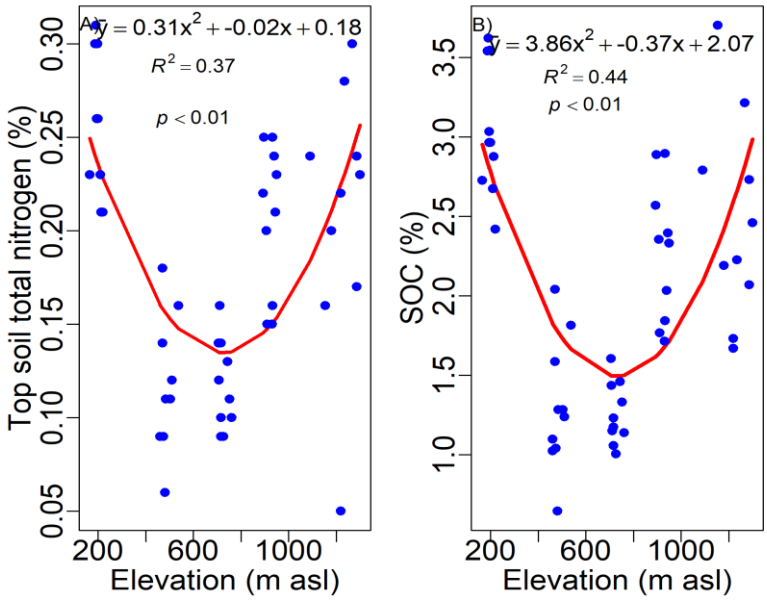


Figure 25: Relationship of elevation to A) total nitrogen and B) soil organic carbon of soil taken at 0-15 cm depth. The fitted line is the polynomial second-order linear model (lm). The equation of the selected model (fitted line) is given with coefficient of determination (R^2) and probability value (*p*-values).

A statistically significant reversed hump-shaped relationship between elevation, total nitrogen, and SOC ($p < 0.01$) first indicated a decrease in TN and SOC. It then again increased with increasing elevation (**Figure 25**). Earlier researchers have found mixed types of findings. A study done by Shedayi *et al.*, (2016) found an increasing pattern of SOC and total nitrogen with elevation. Likewise, Yohannes *et al.* (2015) revealed a decreasing trend of SOC with increasing elevation.

4.2.8.3 Pearson's correlation (r^2) among soil variable

Correlation among soil variables at 0-15 cm soil depth

Porosity (Por1) and sand1 demonstrated significant positive correlation with elevation. Elevation had more significant negative relation between sil1 and moi1.

Clay1 showed highly significant negative relation with N1, K1 and sand1, whereas highly negative significant relation with P1. BD1 indicated significant correlation with N1 and moi1. In the same way, SOC st1 had highly significant correlation with Nst1, N1, P1, K1, moi1 and OC1, while it showed strongly significant association with clay1 (**Table 28**).

Table 28: Pearson's correlation coefficient (r^2) among soil variables in 0-15 cm depth.

	Elev	N1	P1	K1	pH1	Sand1	Clay1	Sil1	Moi1	WHC1	BD1	Por1	OC1	C:N1	SOCst1
Elev															
N1	-0.04														
P1	-0.56***	0.49***													
K1	0	0.60***	0.46***												
pH1	-0.63***	0.1	0.36*	0.08											
Sand1	0.29*	0.40**	0.07	0.51***	-0.14										
Clay1	0.06	-0.53***	-0.30*	-0.56***	-0.16	-0.79***									
Sil1	-0.40**	-0.28	0.04	-0.45**	0.24	-0.94***	0.61***								
Moi1	-0.41**	0.46***	0.45**	0.22	0.23	-0.35*	0.05	0.41**							
WHC1	0.26	0.32*	0.27	0.26	-0.14	0.09	0.01	-0.11	0.31*						
BD1	-0.21	0.40**	0.26	-0.01	0.17	-0.03	-0.07	0.05	0.45**	0.21					
Por1	0.33*	0.31*	0.03	0.1	0.08	0.29*	-0.19	-0.29*	0.04	0.26	0.31*				
OC1	-0.06	0.88***	0.51***	0.60***	0.14	0.38**	-0.54***	-0.26	0.49***	0.40**	0.44**	0.35*			
C:N1	0.16	-0.28	-0.02	-0.01	-0.03	-0.01	0.04	-0.03	0.03	0.49***	0.08	0.16	0.13		
SOCst1	-0.26	0.78***	0.53***	0.58***	0.14	0.22	-0.46***	-0.09	0.54***	0.35*	0.37**	-0.11	0.88***	0.06	
Nst1	-0.25	0.87***	0.50***	0.57***	0.11	0.22	-0.42**	-0.09	0.51***	0.27	0.31*	-0.17	0.75***	-0.30*	0.90***

$P < 0.001$ = "***", $p < 0.01$ = "** " and $p < 0.05$ = "* ", Elev= Elevation; N1= Nitrogen; P1=Phosphorus; K1= Potassium; Sil1= Silt; Moi1= Moisture; Por= Porosity; OC1= Organic carbon; SOCst1= SOC stock; Nst= Nitrogen stock at upper soil layer (0-15 cm).

Correlation among soil variable at 15-30 cm soil depth

Table 29 demonstrated that OC2 showed significant correlation to P2, and Moi2 ($p < 0.05$). Likewise, it demonstrated more significant association ($p < 0.01$) with sil2and Por2, whereas, it resulted highly significant relationship with the N2, K2, Sand2, Clay2 and BD2.

P2 had significant correlation with N2, while strong significant relation to the Alt.

Furthermore, K2 demonstrated significant relationship with P2 and it showed highly significant correlation with N2.

Table 29: Pearson's correlation coefficient (r^2) among soil variables 15 -30 cm depth.

	Elev	N2	P2	K2	pH2	Sand2	Clay2	Sil2	Moi2	WHC2	BD2	Por2	OC2	C:N2	SOCst2
N2	0.11														
P2	-0.52***	0.43**													
K2	0.02	0.59***	0.44**												
pH2	-0.48***	0.14	0.43**	0.35*											
Sand2	-0.04	0.49***	0.42**	0.57***	0.30*										
Clay2	0.31*	-0.43**	-0.47***	-0.45**	-0.51***	-0.83***									
Sil2	-0.07	-0.41**	-0.36*	-0.52***	-0.21	-0.93***	0.64***								
Moi2	-0.23	0.44**	0.37**	0.27	0.22	0.03	-0.19	0.07							
WHC2	0.11	0.27	0.17	0.14	-0.09	0.08	-0.06	-0.05	0.05						
BD2	-0.17	0.48***	0.26	0.01	0.06	0.08	-0.23	0.03	0.43**	-0.07					
Por2	0.28	0.41**	0.04	0.17	0.05	0.25	-0.28*	-0.14	0.2	0.1	0.38**				
OC2	0.05	0.92***	0.35*	0.51***	0.18	0.52***	-0.50***	-0.42**	0.33*	0.13	0.48***	0.44**			
C:N2	-0.24	-0.27	-0.13	-0.21	0.13	0.02	-0.15	0.02	-0.30*	-0.41**	0.03	-0.05	0.1		
SOCst2	-0.12	0.83***	0.39**	0.47***	0.21	0.37**	-0.41**	-0.29*	0.41**	0.03	0.48***	0.09	0.89***	0.09	
Nst2	-0.06	0.90***	0.48***	0.56***	0.18	0.35*	-0.33*	-0.28	0.51***	0.18	0.46***	0.08	0.79***	-0.29*	0.91***

$P < 0.001$ = "***", $p < 0.01$ = "** " and $p < 0.05$ = "* ", Elev= Elevation; N2= Nitrogen; P2=Phosphorus; K2= Potassium; Sil2= Silt; Moi2= Moisture; Por2= Porosity; OC2= Organic carbon; SOCst2= SOC stock and Nst2= Nitrogen stock at lower soil layer (15-30 cm).

4.2.9 Relation between vegetation and environmental factors combining all forests

Redundancy Analysis (RDA) among total species and environmental factors

The first axis of RDA clearly represented elevation. The positive end of the RDA first showed the Sagma forest gradient. The higher abundance of Thunb.ala, Age.adeno is unique of this high elevation forest. The soil of this forest had a lesser pH at both layers. The positive end of the RDA second axis was clearly represented by the Murchungi and Rajarani forests, having a high C: N ratio of the second layer and both soils were clay. Soil organic matter, Nitrogen, SOC, WHC1 and BD of both layers of the Bhaunne forest were represented by the negative end of the RDA second axis (**Figure 26**).

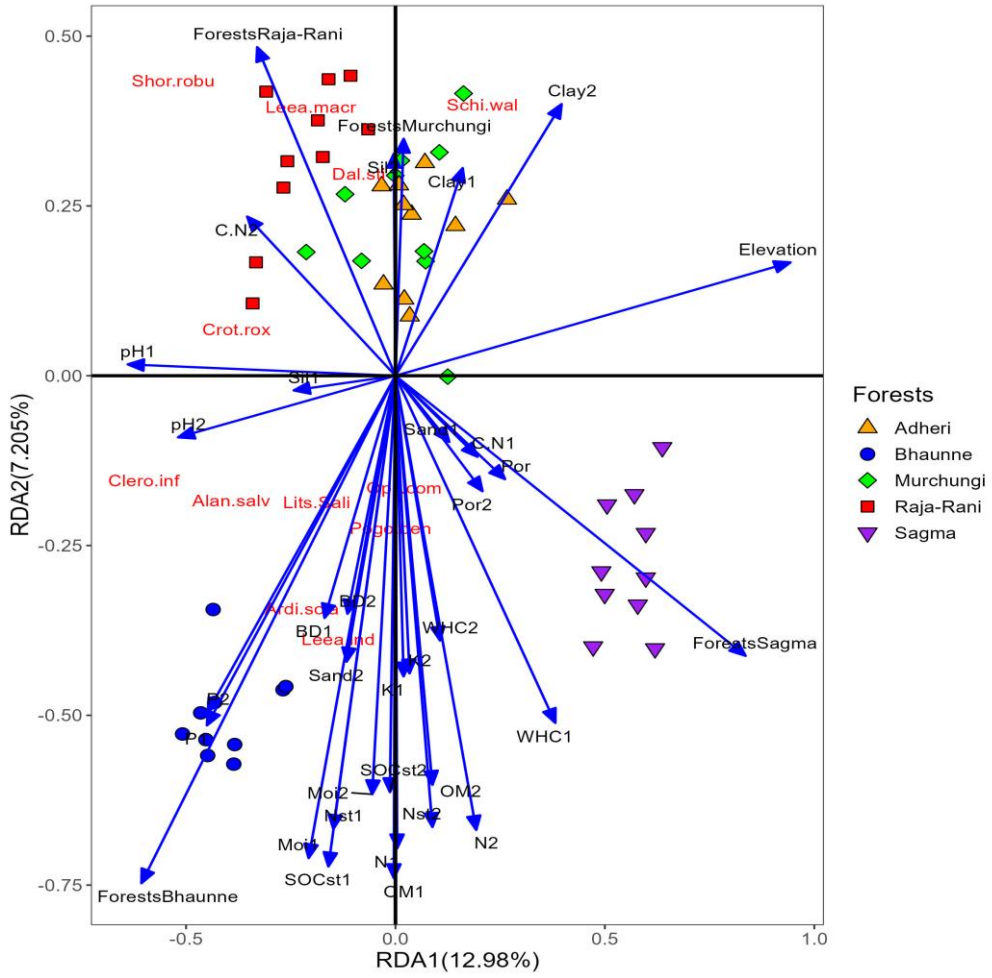


Figure 26: RDA ordination bi-plot of all plants of 50 plots and 34 environmental variables of five forests. Full forms of all species abbreviation were given in an Appendix I.

High abundance of *Shorea robusta, Leea macrophylla, Dalbergia stipulata*, *Croton roxburghi* highly correlated with Rajarani forest. Murchungi was highly correlated with a high abundance of *Schima wallichii* which favored clay soil. High abundance of *Ardisia solanacea, Leea indica,* and *Pogostemon benghalensis* were highly correlated with soil chemical variables.

Redundancy analysis (RDA) of herb species and environmental variables

Elevation showed statistically significant representation by the second axis of RDA. Raja-Rani forest gradients represented by the positive end of the first axis of the RDA located towards the lowest elevation in this study. High abundance of *Koenigia mollis, Axonopus compressus, Cyperus brevifolia*, and *Commelina suffruticosa* towards the positive end of the first axis of the RDA and in Raja-Rani forest were significantly explained by high amount of BD1, BD2, Sil2, Clay1 etc.

High abundance of *Imperata cylindrica, Elsholtzia blanda, Paspalum conjugatum, Barleria cristata, Strobilanthes capitata, Achyranthes bidentata* were unique to high elevation forests such as Adheri and Sagma were significantly represented by the negative end of the RDA first axis. Soil of this forest had high WHC, C: N1, Sand1, Por2 and Por1.

Further, high abundance of *Cyanadon dactylon, Alysicarpus vaginalis, and Oplimenus composites* towards Murchungi forest associated with high value of OM1, OM2, N2, K2, WHC1, NST1, NST2, SOCst1, and SOCst2.

Bhaunne forest was correlated with high abundance of *Pogostemon benghalensis, Oxalis corniculata,* and *Synedrella nodiflora*. High abundance of those herb species were associated with high amount of soilP1, P2, Moi1, Moi2 (**Figure 27**). However, both the RDA1 and RDA2 explained very low (7 and 6 %) variance respectively. It would be various reasons such as high heterogeneity of the habitat that could not addressed by the measured environmental variables, or multicollinearity in the predictors or noise in the data.

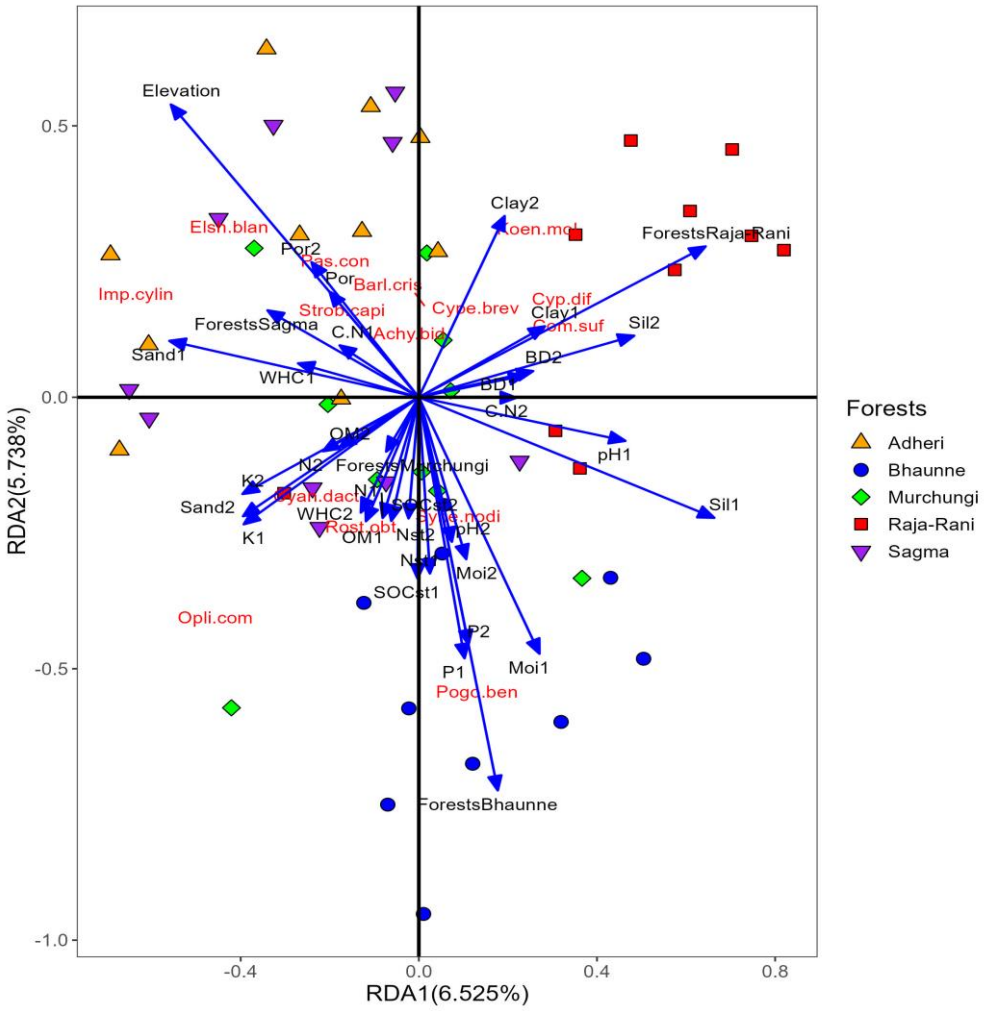


Figure 27: RDA ordination bi-plot of herbs of 50 plots and 34 environmental variables of five forests. Full forms of all species abbreviation were given in an Appendix I.

Redundancy analysis (RDA) of shrub species and environmental variables

The second axis of RDA clearly represented elevation. The positive end of the RDA first showed the Murchungi and Raja-Rani forests gradient. The higher abundance of *Malastoma malaberica* is highly related with Sagma and is associated with high WHC1, WHC2, Por1, Por2, K1, K2, Sand2, Sand 1, C: N1, N1, and N2. The positive end of the RDA first axis was clearly represented by the Bhaunne forest highly correlated with high abundance of *Leea indica*, *Ardisia solanacea*, and *Litsea salicifolia*.

The Bhaunne forest showed highly correlated with high P1, P2, SOCst2, Nst2, pH1, Moi1, Moi2, BD1, BD2 and pH2. Abundance of *Maesa macrophylaa* is highly positively correlated with Adheri forest gradient had high clay 2, C: N1. and elevation gradient. Similarly, abundance of *Leucomeris spectabilis and Combretum roxburghi*

were correlated with Murchungi forest and this forest was associated with high clay 1, clay 2, and sil2. Further, high abundance of *Leea macrophylla, Maesa chisia, Clerodrendron infortunatum, Bergera koenigii* and *Combretum roxburghii* are correlated with Raja-Rani forest with high C: N2, Clay1, Sil1, and Sil2 (**Figure 28**).

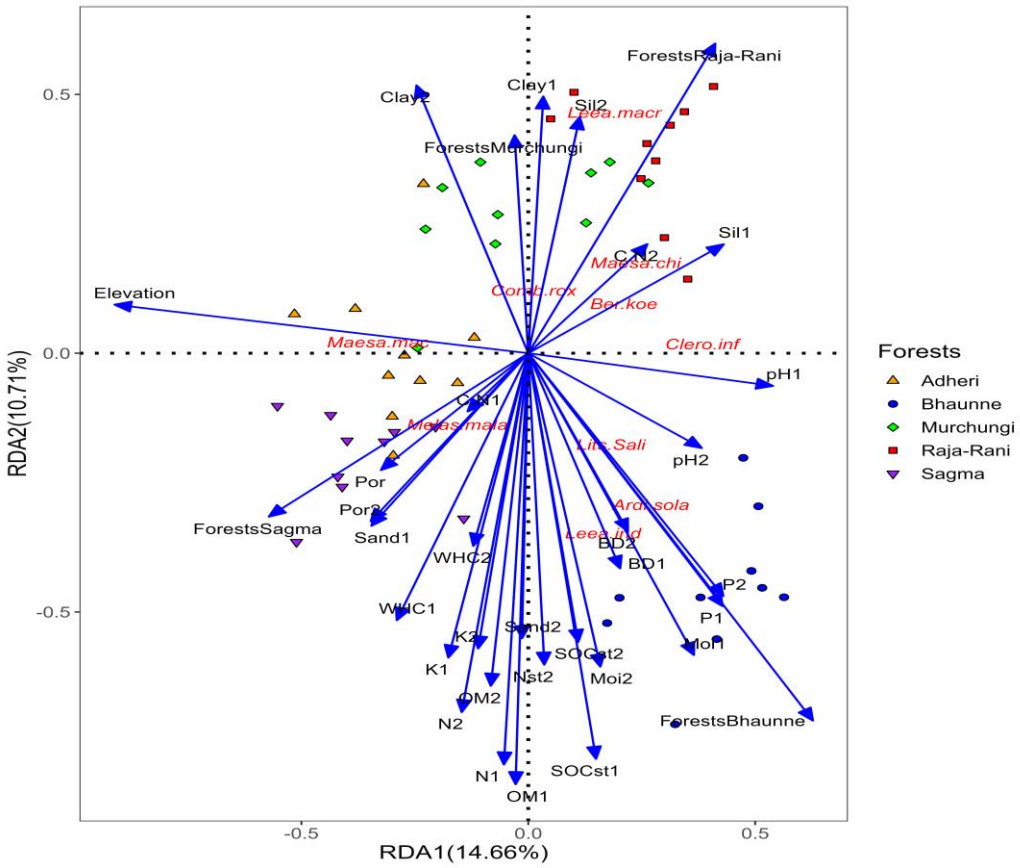


Figure 28: RDA ordination bi-plot of shrubs of 50 plots and 34 environmental variables of five forests. Full forms of all species abbreviation were given in an Appendix I.

Redundancy analysis (RDA) of tree species and environmental variables

The first axis of RDA clearly represented elevation. The positive end of the RDA second showed the Bhaunne and Raja-Rani forests gradient.

The higher abundance of *Litsea monopetala, Schima wallichii, Castanopsis indica, Alnus nepalensis* and *Engelhardia spicata* are highly correlated with Sagma forest with high WHC1, Clay1, Clay2, Por1, Por2, Nst2, N2, OM2, SOCst2, BD2, and Sil2.

Similarly, abundance of *Dalbergia stipulate, Actinodaphne lanceolata* and *Shorea robusta* are correlated with Murchungi and Adheri forest. Murchungi forest were with high Sand1, Sand2, K1, K2, and C: N2. And Adheri forest associated with high

Sand1, and K1 On the otherhand, abundance of *Alstonia scholaris*, *Alangium salviifolium*, *Ehretia acuminate*, *Lagerstroemia parviflora*, and *Croton persimilis* are associated with Bhaunne and Raja-Rani forest. *Mallotus philipensis* also associated with Raja-Rani forest having high soil variables such as Nst1, Nst2, SOCst1, pH1, BD1, BD2, OM1, OM2, N2, Sil1, Sil2, and WHC2 etc. Bhaunne forest was having high P1, P2, Nst1, SOCst1, pH1, BD1, and OM1 (**Figure 29**).

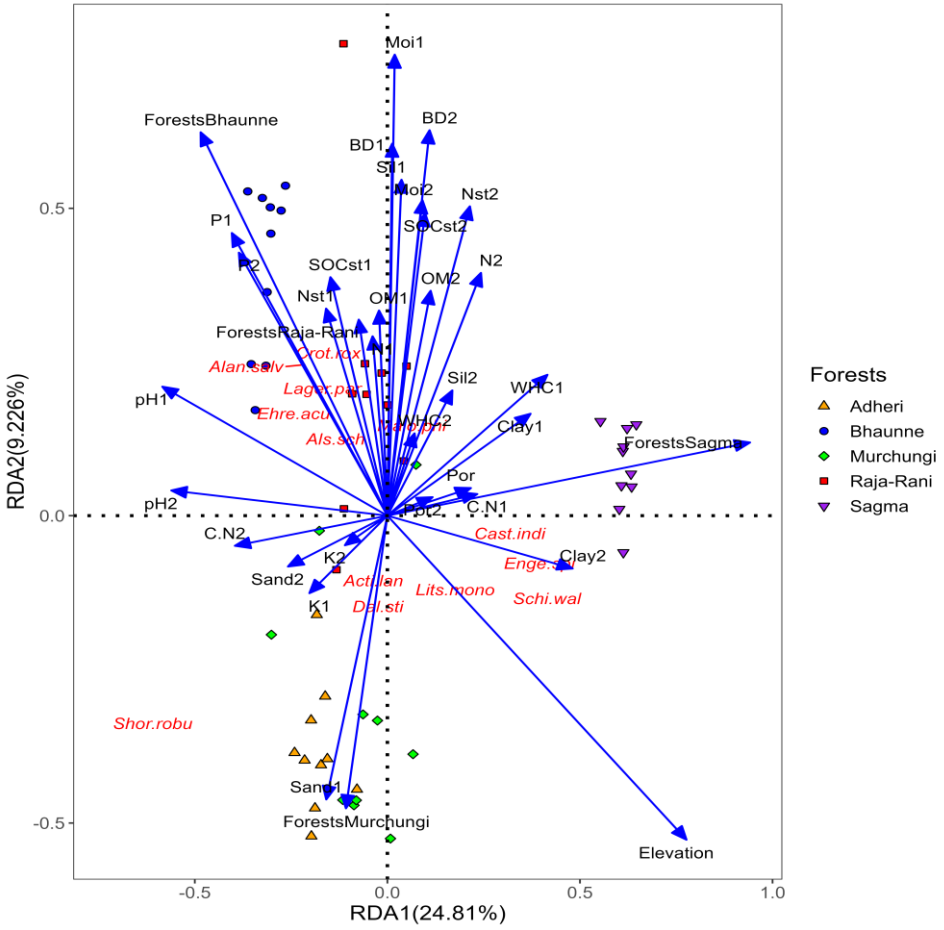


Figure 29: RDA ordination biplot of trees of 50 plots and 34 environmental variables of five forests. Full forms of all species abbreviation were given in an Appendix I.

4.2.10 IUCN Red -list categories and CITES listed plants in the forests

Out of 315 total plant species in this study, 123 were classified as Least Concern (LC) on the IUCN Red List. *Dalbergia latifolia* Roxb. and *Albizia julibrissin* Durazz. were classified as Vulnerable (VU), and *Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Sweet was classified as Extinct in the Wild (EW). Aegle marmelos (L.) Correa was categorized as Near Threatened (NT), whereas, Actinodaphne lanceolata Daizell & A. Gibson. and Elaeodendron glaucum (Rottb.) Pers. Classified as Data

Deficient. Additionally, three species: *Dalbergia latifolia* Roxb., *Dalbergia sissoo* Roxb., and *Rauvolfia serpentina* (L.) Benth. ex Kurz were listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) (**Appendix I**).

Moreover, six problematic invasive alien plant species were identified in these forests: *Ageratina adenophora* (Spreng.) R. M. King & H. Rob., *Ageratum conyzoides* L., *Bidens pilosa* L., *Chromolaena odorata* (L.) R. M. King & H. Rob., *Lantana camara* L., and *Mikania micrantha* Kunth (**Table 30**).

The classification of 123 out of 315 plant species as Least Concern (LC) highlights the relatively stable status of the majority of species in this study area. This finding suggests that these species are not currently facing significant threats and may have stable or expanding populations. However, it is important to continuously monitor these species as environmental conditions and threats evolve.

The identification of *Dalbergia latifolia* Roxb. and *Albizia julibrissin* Durazz. as Vulnerable (VU) and *Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Sweet as Extinct in the Wild (EW) underscores the conservation challenges faced by certain species. *Dalbergia latifolia* Roxb. is valued for its timber, which has led to overharvesting and habitat loss, contributing to its Vulnerable status. *Brugmansia suaveolens*, on the other hand, is critically endangered in the wild, with remaining populations possibly limited to cultivation or controlled environments (IUCN, 2023).

The listing of *Dalbergia latifolia* Roxb., *Dalbergia sissoo* Roxb., and *Rauvolfia serpentina* (L.) Benth. ex Kurz in Appendix II of CITES highlights their importance in international trade and the need for regulated trade practices to prevent overexploitation. *Dalbergia sissoo* Roxb., commonly known as Indian Rosewood, is particularly significant due to its economic value and the pressures from logging (Gillespie *et al*., 2023).

The presence of six problematic invasive alien plant species; *Ageratina adenophora* (Spreng.) R. M. King & H. Rob., *Ageratum conyzoides* L., *Bidens pilosa* L., *Chromolaena odorata* (L.) R. M. King & H. Rob., *Lantana camara* L., and *Mikania micrantha* Kunth raises concerns about ecosystem health. These species are known for their aggressive growth and competition with native flora, often leading to significant ecological and economic impacts. Recent studies have shown that invasive

species like these can severely disrupt local biodiversity, outcompeting native species and altering habitat structure (Lázaro-Lobo *et al*., 2023; Gupta *et al*., 2021).

In conclusion, many species in the study area are currently classified as Least Concern, the presence of vulnerable and critically endangered species, together with invasive alien species, indicates ongoing conservation challenges. Addressing these issues through targeted conservation efforts and monitoring is essential for maintaining biodiversity and ecosystem health especially Sagma, the high elevation forest and Bhaunne the low elevation forest.

Table 30: Problematic invasive alien plants found in the studied forests.

S.N	Scientific Name
1	*Ageratina adenophora* (Spreng.) R. M. King & H. Rob.
2	*Ageratum conyzoides* L.
3	*Bidens pilosa* L.
4	*Chromolaena odorata* (L.) R. M. King & H. Rob.
5	*Lantana camara* L.
6	*Mikania micrantha* Kunth

4.2.11 Final best selection of variables

A multiple linear regression model identified Mois1, FR1P25 and FR125 as significant predictors of tree species (Trsp) expression. These variables exhibited strong associations with Trsp expression (Mois1: $p < 0.001$, FR1P25: $p < 0.01$, FR125: $p < 0.05$). The final selected model yielded an R-squared value of 0.47 indicating that 47% of the variance in Trsp expression was explained by the selected variables. The positive coefficient of Mois1 and FR1P25 suggested that an increase in Mois1 and FR1P25 values was associated with a higher expression of Trsp, which is agreement with Sun *et al*. (2017). Conversely, the negative coefficient of FR125 indicated a negative relationship with Trsp expression (**Table 31**).

Table 31: Best variables after model selection: Tree species richness.

Term	Estimate	Std.error	t-value	p-value
(Intercept)	8.89	1.19	7.45	< 0.001
Mois1	0.27	0.07	3.98	< 0.001
FR1P25	736.55	282.99	2.60	< 0.01
FR125	-1.53	0.77	-1.98	< 0.05
Residual standard error: 2.384 on 46 degrees of freedom, Multiple R-squared: 0.4723, Adjusted R-squared: 0.4379, F-statistic: 13.72 on 3 and 46 DF, *p* - value: 1.593e-06.				

Note: Trsp: tree species, Mois1: moisture, FR125: fine root biomass of 2-5 mm diameter, FR1P25: Phosphorous in 2-5 mm diameter fine root biomass. These variables are concerned in 0-15 cm soil depth.

The model identified Elev, Mois1 and NLP as significant predictors of shrub species richness, exhibited strong associations with Ssp. expression (Elev: $p < 0.001$, Mois1: $p < 0.001$, NLP: $p < 0.05$). The final selected model yielded an R-squared value of 0.69 indicating that 70% of the variance in Ssp expression was explained by the selected variables. All positive coefficients of Elev, Mois1 and NLP suggested that an increase in Elev, Mois1 and NLP values was associated with a higher expression of Ssp (**Table 32**).

Table 32: Best variables after model selection: Shrub species richness.

Term	Estimate	Std.error	t-value	p-value
(Intercept)	3.77	1.04	3.61	< 0.001
Elev	0.01	0.00	9.61	< 0.001
Mois1	0.15	0.05	3.09	< 0.001
NLP	7.18	3.68	1.95	< 0.05
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 1.727 on 46 degrees of freedom, Multiple R-squared: 0.6859, Adjusted R-squared: 0.6654, F-statistic: 33.49 on 3 and 46 DF, *p*-value: 1.244e-11.				

Note: Ssp: Shrub species, Mois1: moisture at 0-15 cm depth, NLP: Non leaf phosphorous, Elev: Elevation.

The model identified TN2, Clay2, and LK as significant predictors of Hsp expression. These variables exhibited strong associations with Hsp expression (TN2: $p < 0.001$, Clay2: $p < 0.001$, LK: $p < 0.01$). The final selected model yielded an R-squared value

of 0.50 indicating that 50% of the variance in Hsp expression was explained by the selected variables. Similarly, positive coefficients of TN2 and Clay2 suggested that an increase in TN2 and Clay2 was associated with a higher expression of Hsp Conversely, the negative coefficient of LK indicated a negative relationship with Hsp expression (**Table 33**).

Table 33: Best variables after model selection: Herb species richness.

Term	Estimate	Std.error	t-value	p.value
(Intercept)	5.98	1.76	3.39	< 0.001
TN2	32.30	5.94	5.44	< 0.001
Clay2	0.26	0.08	3.36	< 0.001
LK	-1.11	0.43	-2.56	< 0.01
Residual standard error: 2.344 on 46 degrees of freedom, Multiple R-squared: 0.503, Adjusted R-squared: 0.4706, F-statistic: 15.52 on 3 and 46 DF, *p*-value: 4.132e-07.				

Note: TN2: Total Nitrogen at 15-30 cm depth, Clay2: Clay at 15-30 cm depth, LK: Leaf potassium.

A multiple linear regression model identified elevation (Elev), Potassium in fine root biomass of <2mm size at 15-30 cm soil depth (FR2Kle2) and pH at 0-15 cm depth (pH1) as significant predictors of tree biomass expression. These variables exhibited strong associations with tree biomass expression (Elev: $p < 0.05$, FR2Kle2: $p < 0.05$, pH1: $p < 0.05$). The final selected model yielded an R-squared value of 0.47 indicating that 40% of the variance in tree biomass expression was explained by the selected variables. The positive coefficient of pH suggested that an increase in pH values was associated with a higher expression of tree biomass. Conversely, the negative coefficient of elevation and FR2Kle2 indicated a negative relationship with tree biomass expression (**Table 34**).

Table 34: Best variables after model selection: Tree biomass.

Term	Estimate	Std.error	t-value	p.value
(Intercept)	-914.65	1063.77	-0.86	<0.05
Elev	-0.37	0.17	-2.15	< 0.05
FR2Kle2	-192.45	92.90	-2.07	< 0.05
pH1	310.27	181.95	1.71	<0.05
Residual standard error: 317.5 on 46 degrees of freedom, Multiple R-squared: 0.4061, Adjusted R-squared: 0.3674, F-statistic: 10.49 on 3 and 46 DF, *p*-value: 2.249e-05.				

Note: Elev: Elevation, FR2Kle2: Potassium of fine root biomass (<2 mm) of 15-30 cm soil depth, pH1: pH at 0-15 cm soil depth.

The model identified MTFR (mean total fine root), FR2P25 (amount of phosphorus of fine root of 2-5mm diameter size at 15-30cm soil depth), pH1 (pH of upper soil depth), P2 (phosphorus of 15-30 am soil depth), and BD2 (bulk density at 15-30cm soil depth) as significant predictors of shrub biomass expression. These variables exhibited strong associations with shrub biomass expression (MTFR: $p < 0.05$, FR2P25: $p < 0.001$, pH1: $p < 0.001$, P2: $p > 0.05$, BD2>0.05). The final selected model yielded an R-squared value of 0.35 indicating that 35% of the variance in shrub biomass expression was explained by the selected variables. All positive coefficients of FR2P25, P2, and BD2 suggested that an increase in FR2P25, P2, and BD2 values was associated with a higher expression of shrub biomass (**Table 35**).

Table 35: Best variables after model selection: Shrub biomass.

Term	Estimate	Std.error	t-value	p.value
(Intercept)	1.31	0.40	3.24	<0.001
MTFR	-0.02	0.01	-2.33	<0.05
FR2P25	26.74	8.60	3.11	<0.001
pH1	-0.20	0.07	-2.76	<0.001
P2	0.00	0.00	-1.29	0.204
BD2	0.13	0.08	1.58	0.121

Residual standard error: 0.1493 on 44 degrees of freedom, Multiple R-squared: 0.3568, Adjusted R-squared: 0.2838, F-statistic: 4.883 on 5 and 44 DF, *p*-value: 0.001223.

Note: MTFR: mean total fine root, FR2P25: phosphorus of fine root biomass (2-5 mm) of 15-30 cm depth.

The model identified OM2, K2, and WHC2 as significant predictors of herb biomass expression. These variables exhibited strong associations with herb biomass expression (OM2: $p < 0.05$, K2: $p < 0.001$, WHC2: $p < 0.001$). The final selected model yielded an R-squared value of 0.34 indicating that 34% of the variance in herb biomass expression was explained by the selected variables. Similarly, positive coefficients of OM2 and WHC2 suggested that an increase in OM2 and WHC2 was associated with a higher expression of herb biomass. Conversely, the negative coefficient of K2 indicated a negative relationship with herb biomass expression (**Table 36**).

Table 36: Best variables after model selection: Herb biomass.

Term	Estimate	Std.error	t-value	p.value
(Intercept)	-17.647	5.811	-3.037	<0.001
OM2	3.875	1.455	2.663	<0.05
K2	-0.032	0.011	-3.000	<0.001
WHC2	0.205	0.056	3.692	<0.001

Residual standard error: 10.38 on 46 degrees of freedom, Multiple R-squared: 0.3437, Adjusted R-squared: 0.3009, F-statistic: 8.031 on 3 and 46 DF, *p*-value: 0.0002078.

Note: OM2: Organic matter, K2: Potassium, WHC2: Water holding capacity. All these variables are concern lower depth (15-30 cm).

CHAPTER 5

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The variation in elevation of the study area leads to difference in climatic condition which caused differences in soil properties and plant properties as concluded below:

- As elevation increases total species richness, herb and shrub species richness significantly increases but tree species richness significantly decreases.
- As the elevation increases, the total plant biomass and tree biomass significantly decreases. Shrub biomass increases but not significant, whereas, herb biomass increases significantly with increasing elevation.
- In the litter mass, leaf litter stands for a favorable mechanism of nutrient release in the ecosystem as it has narrow C: N ratio.
- Likewise, fine roots of <2mm diameter size having higher biomass value also contained narrow C: N ratio, which reflects an indication of fast release of nutrients under decomposition process.
- A statistically significant reversed hump-shaped relationship between elevation, total nitrogen, and SOC ($p < 0.01$) first indicating a decrease in TN and SOC. It then again increases with increasing elevation.
- Forest at lower elevation (Bhaunne forest) considered as more productive as indicated by rich plant diversity, biomass, carbon and nutrient stocks which accumulate together interdependently.

5.2 Recommendation

- On the basis of present findings, the suitable ecological niche for *Shorea robusta* is considered as low elevation forest (200 m) like Bhaunne. Sal bearing mixed forests should be conserved at this region properly.
- The forest at low elevation, 200 m (Bhaunne) is rich in biodiversity, biomass and ultimately the storage tank of carbon. Hence, it should be managed properly to maintain the same species composition and structure in other forests. Therefore, it is useful to set the mitigation measures.

- To achieve the complete information on structure and functioning of forests of this region, work on forest production, carbon sequestration and litter fall are essential to be done to draw the mechanism of nutrient cycling.
- The high number of unique species and clusters in the forests highlights their role in maintaining regional biodiversity. Therefore, conservation strategies should prioritize protecting these areas from environmental degradation to preserve their ecological integrity. So, it may be the guideline for the policy makers in developing the sound strategies and planning for the conservation and sustainable management of forest ecosystem.
- The findings obtained may be the references for the researchers and academicians.

CHAPTER 6

6. SUMMARY

Present study aimed to determine the changes in plant species composition, forest structure, stand biomass, litter mass, fine roots and their carbon stocks along the five forests located at different elevations: Bhaunne (200 m), Raja-Rani (500 m), Murchungi (800 m), Adheri (1000 m), and Sagma (1200 m). nutrient stocks were also estimated in litter mass, the aboveground source and fine roots; the below ground source of nutrients.

The study was carried out in five forests located at different elevational gradient in Morang district of east Nepal (latitude 26°39'45.69" N to 26°48'28.68" N and longitude 87°28'2.08" E to 87°28'45.06" E), within the elevation range of 100 to 1300 m masl. The climate is tropical monsoon type. The mean annual minimum temperature ranges from 11°C to 25°C and maximum temperature range from 21°C to 35°C. The average annual rainfall ranged from 2.8 mm to 551.2 mm in Bhaunne to Murchungi forest. On the other hand, average minimum and maximum annual temperature and of Adheri and Sagma forest range from 7°C to 21°C, 20°C to 30°C respectively. The average annual rainfall ranged between 1 mm in November to 259 mm in July.

Among total 315 species, 21 plant species were common to all the five forests. The total numbers of species were 142 and 126 in Bhaunne and Raja-Rani forest respectively, and 121 species in both Murchungi and Adheri forests, and 137 species in Sagma forest. Plant species are belonged to 250 genera, and 82 families. 143 herbs belonged to 35 families and 112 genera. Likewise, 69 species of Shrubs are belonging to 35 families.

Density and girth values of herbs, shrubs and trees varied with elevations. The distinct differences in density and girth class distribution were observed in five different forests. Stand density of trees (individual ha^{-1}) ranged from 602.5 in Sagma to 985 in Adheri forest. Decreased density in Sagma forest was due to environmental factors. The density of trees was high in 10-50cm girth class in all forests. The tree species having 10-50 cm girth class shared 39 %, 51 %, 40 %, 41 % and 52% to the total tree species of Bhaunne, Raja-Rani, Murchungi, Adheri and Sagma forest respectively.

The density of herbs and shrubs were maximum at Sagma forest due to minimum density of trees. Similarly, the basal area of shrub was maximum at Sagma forest while basal area of trees was minimum at the forest. Based on species IVI of tree, *Shorea robusta* was dominant in Bhaunne (200 m), Raja-Rani (500 m), Murchungi (800 m) and Adheri (1000 m) forest. While, *Schima wallichii* was dominant in Sagma (1200 m) forest.

Shannon-Wiener index of species diversity and species richness of herbs ranged from 3.65 to 3.79 and 14.81 to 19.3 respectively, similarly that of shrubs ranged from 2.2 to 2.98 and 2.09 to 3.86, minimum at Bhaunne forest and maximum at Sagma forest, that shows increasing pattern with increasing elevation. Shannon-Wiener index of trees ranged from 2.22 to 3.12, minimum at Adheri and maximum at Sagma forest. Species richness of trees ranged from 5.94 to 8.48, minimum at Sagma and maximum at Bhaunne forest, which showed decreasing pattern with elevation.

Herb species richness was significantly (p = <0.0001) different between Bhaunne and Sagma, Raja-Rani and Sagma, Murchungi and Sagma and Adheri and Sagma forest. Shrub species richness of Sagma forest was significantly (p = <0.0001) different with all the other four forests. Tree species richness was significantly (p = 0.0095) different between Bhaunne and Adheri forest. Total species richness (combing herbs, shrubs and trees) of forest significantly (p = 0.00013) different between Sagma and Adheri forest, Sagma and Bhaunne forest etc.

Similarity index for herb species exhibited minimum value; 28 % between Bhaunne and Sagma forest and maximum values (46%) were seen between Raja-Rani and Murchungi forest. In case of shrubs minimum similarity percentage (36%) were found between Bhaunne and Adheri forest, while maximum value (75%) were recorded between Murchungi and Adheri forest. On the other hand, in case of trees similarity index values were minimum (22%) between Bhaunne (200 m) and Sagma (1200 m) forest and maximum values (64%) were between Murchungi and Adheri forest.

With increasing elevation, there was a statistically significant (D^2=0.11, p < 0.01) linearly inclined relation observed in the herbs species. This result was consistent with the overall species richness. The shrub species richness (number of shrub species) showed statistically significant (D^2=0.61, p < 0) inclined relationship with increasing elevation. Thus herbs, shrubs and total species richness rejected the hypothesis. In a

similar way, the tree species richness, decreased linearly with increasing elevation and was statistically significant (D^2=0.12, p < 0.01), which follow the proposed hypothesis.

However, high species number of herbs and trees in Bhaunne forest (200 m) may be due to high turnover rate of organic matter favoring high rate of photosynthesis. Conversely, lower number of shrub species in Bhaunne could be attributed to the dense canopy of trees which tend to suppress the undergrowth from obtaining sufficient sunlight required for germination, growth and development in light loving species. The higher tree species richness in Bhaunne forest may be due to higher soil moisture and nutrients.

On the other hand, less number of tree species in Sagma forest (1200 m) may be due to decrease in temperature along elevation that slow down litter mass decomposition and fine root turnover rate.

Stand biomass is distinctly affected by the elevation. The highest stand biomass (815.86 Mg ha^{-1} equivalent to 333.63 Mg C ha^{-1}) at Bhaunne (low elevation, 200 m) forest may be related to the presence of more trees of larger girth classes. On the other hand, lower stand biomass (299.96 Mg ha^{-1} equivalent to 140.19 Mg C ha^{-1}) in Sagma forest (1200 m) may be due to less number of tree species with low girth class. The tree biomass also decreased with increasing elevation from 796.46 Mg ha^{-1} in Bhaunne forest to 265.23 Mg ha^{-1}in Sagma forest. The tree biomass in Bhaunne and Sagma forest, Murchungi and Sagma forest was significantly different. Shrubs and herbs biomass were maximum at Sagma forest due to less tree density and biomass.

The statistical significant decline in the total biomass and tree biomass with elevation aligns with the proposed hypothesis in this study. While, herb biomass statistically significantly inclined and shrub biomass also inclined (but not significantly) with increase of elevation, rejects the proposed hypothesis. Total biomass and tree biomass decreased with increase of species richness, which rejected the proposed hypothesis, while, herb biomass and shrub biomass increased, when elevation increased, accepting the hypothesis.

Litter mass in Raja-Rani forest has maximum value (25.7 Mg ha^{-1} and Adheri forest has minimum value (7.1 Mg ha^{-1}). The leaf litter mass was highest (7.1 Mg ha^{-1}) in Bhaunne forest and lowest (1.4 Mg ha^{-1}) in Sagma forest. The partially decomposed

litter mass was maximum in Raja-Rani forest (3.0 Mg ha^{-1}) and minimum in Adheri forest (1.7 Mg ha^{-1}).

Non-leaf litter (wood litter) mass was maximum in Sagma forest 21.5 Mg ha^{-1}) and minimum in Adheri forest (1.8 Mg ha^{-1}). The accumulation of higher wood mass at Sagma forest may be due to slower turnover rate due to decreased temperature at high elevation. The highest litter mass carbon stock was recorded in Sagma forest (13.37 Mg C ha^{-1}) because of high wood litter mass and minimum in Adheri forest (3.66 Mg C ha^{-1}). The total litter mass carbon stock of different five forests were in the order of Sagma> Raja-Rani> Bhaunne> Murchungi> Adheri. In Bhaunne, Murchungi and Adheri forest leaf litter component contributed higher amount of carbon to the total carbon, while in Raja-Rani and Sagma forest maximum contribution of carbon stock was seen from non -leaf (wood) components.

So far the nutrient concentration is concerned, amongst components, the leaves contained maximum concentrations of nutrients in all forests which make this component an important reserve of nutrients. N, P and K concentrations in the litter mass components were in the order of: leaf > partially decomposed > non-leaf components. Nutrient stocks in non-leaf litter mass were higher than leaf litter in all the forests due to its huge mass. The highest amount of leaf nutrient stocks; N (79.19 Kg ha^{-1}), P (0.02 Kg ha^{-1}) and K (2.63 Kg $ha^{-1)}$ were recorded in Bhaunne forest, and the lowest amount of N (21.46 Kg ha^{-1}), P (0.004 Kg $ha^{-1)}$ and K (0.75 Kg ha^{-1}) in Sagma forest. In non-leaf litter maximum N (173.75 Kg ha^{-1}) and K (5.38 Kg ha^{-1}) were at Raja-Rani forest, while amount of P was maximum at Sagma forest. Partially decomposed litter accounted higher amount of N (32.63 Kg ha^{-1}) and K (0.73 Kg ha^{-1}) at Raja-Rani forest and highest amount of P (0.01 Kg ha^{-1}) stock at both Bhaunne and Raja-Rani forests.

Stand fine root were maximum (16 Mg ha^{-1}) in Murchungi forest and minimum (7.14 Mg ha^{-1}) at Bhaunne forest and. Fine root biomass (FRB) was higher in upper soil depth than the lower soil depth in all the five forests. FRB of (< 2 mm in diameter) in both the soil depths were almost double than the 2-5mm diameter sized fine root biomass in all the five forests. The lower FRB in Bhaunne forest could be the result of a higher fine root turnover rate. The amount of littermass, nutrients and organic matter on the soil surface might be the cause for the accumulation of fine roots in the

upper depth. The maximum FRB in Murchungi forest may be due diffirences in soil nutrients.

In search of nutrients maximum fine roots are developed at upper layer (0-15 cm). fine roots of smaller diameter size class (<2 mm) contained quite greater N and P concentrations than that of larger diameter size class (2–5 mm). While K concentration was maximum in 2-5 mm diameter size fine root than <2 mm class. Similarly, nutrient stocks in fineroots were higher in fine roots with <2 mm diameter than the diameter size (2-5 mm). In 0-30 cm soil depth, the fine root of <2mm diameter contained maximum amount of N stock (106.96 Kg ha^{-1}) at Murchungi forest and lowest N stock (48.27 Kg ha^{-1}) at Adheri forest. In case of 2-5 mm diameter fine root maximum N stock (58.54 Kg ha^{-1}) was obtained at Raja-Rani forest. P stock value in total fine root at 0-30 cm soil depth was maximum (0.04 Kg ha^{-1}) at Raja-Rani forest and minimum (0.02 Kg ha^{-1}) at both Bhaunne and Adheri forest. Similarly, K stock was maximum (5.5 Kg ha^{-1}) at Murchungi forest and minimum (2.03 Kg ha^{-1}) at Bhaunne forest at 0-30 cm soil depth.

Soil texture in the study area was ranged from sandy loam to loamy sand both in upper and lower depth. Loamy sand, is considered suitable for regeneration of good Sal and high quality trees. Soil moisture and water holding capacity, bulk density mostly decreased in the lower depth, while soil pH increased. Soil organic carbon (SOC) ranged between 1.26% and 3.04% in the upper soil depth, minimum in Murchungi forest and maximum in Bhaunne forest. Total nitrogen, total phosphorus and potassium were higher in Bhaunne forest in comparision to other forests which might be due to fertile soil and high fine root in lower elevation tropical forest. The higher value of organic matter on the upeer layer may be due to greater inputs of organic matter through the above ground litter decomposition.

Carbon stock in soil varies with elevation and it was highest in low elevation forest (Bhaunne) in comparision to other forests. Pearson's correation revealed BD showed significant correlation ($p < 0.01$) with OM, N, and moisture at upper soil depth (0-15 cm). Likewise, phosphorus and pH showed highly negative significant correlation ($p < 0.001$). Friedman test revealed that total nitrogen mean differences was significant ($p < 0.01$) between Murchungi and Adheri forest, Murchungi and Bhaunne forest, Raja-Rani and Adheri forest.

RDA analysis revealed that in Bhaunne forest *Dillenia pentagyna* shows positive relationship with SOC, silt, pH, moisture, K, TN and clay. *Semecarpus anacardium* shows positive relationship with P and sand of upper soil depth. In Raja-Rani forest phosphorous at lower soil depth have positive relationship with *Mikania micrantha*. Similarly, total nitrogen, SOC of lower soil depth and P of both depth favours *Phyllanthus emblica* and *Syzygium cumini*. *Solanum viarum* have strong negative relationship with moisture of upper depth and SOC and TN of lower depth in Raja-Rani forest. TN at lower depth have positive association with *Clerodendrum japonicum*. At Adheri forest, *Acer oblongum, Elaeodendron glaucum, Diploknema butyracea* are favoured by K of upper soil depth. At Sagma forest clay of upper soil depth and sand at lower layer are favourable for *Ficus neriifolia, Triumfetta pilosa and Rostellularia obtusa.* Likewise, K at both soil depths, TN at lower depth has positive relationship with *Rubus ellipticus.*

The best significant predictors of tree species richness were moisture at 0-15cm depth, amount of phosphorus of fine root biomass (2-5 mm diameter size), and fine root biomass of 2-5 mm diameter size of 0-15cm soil depth. The significant predictors of shrub species richness were elevation, moisture of upper soil surface (at 0-15 cm) and amount of phosphorus in non leaf littermass. While, total nitrogen at lower soil surface (TN2), clay of lower surface (Clay2), and amount of potassium of leaf littermass (LK) as significant predictors of herb species richness.

Elevation (Elev), Potassium in fine root biomass of <2 mm size at 15-30 cm soil depth (FR2Kle2) and pH at 0-15 cm depth (pH1) treated as a significant predictor for tree biomass. Whereas, MTFR (mean total fine root), FR2P25 (amount of phosphorous of fine root of 2-5 mm diameter size at 15-30 cm soil depth), pH1 (pH of upper soil depth), P2 (phosphorus of 15-30 cm soil depth), and BD2 (bulk density at 15-30 cm soil depth) were significant for shrub biomass. Similarly, potassium (K2), and water holding capacity (WHC2) at lower soil surface revealed as significant predictors of herb biomass.

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APPENDICES

Appendix I. List of plant species with their abbreviation

Appendix II.

A. List of publications

B. Participation in Conferences with oral and poster presentation

FIELD PHOTOS

APPENDICES

Appendix I. List of plant species with their abbreviation

Forests	Scientific name	IUCN Red listed/ CITES listed	Abbreviation	Family	Habit
B	*Abutilon indicum* (L.) sweet	-	Abu ind	Malvaceae	H
B,R,M,S	*Achyranthes aspera* L.	-	Achy aspe	Amaranthaceae	H
R,A,S	*Achyranthes bidentata* Blume	-	Achy bid	Amaranthaceae	H
R,S	*Adenostemma lavenia* (L.) Kuntze	-	Aden lav	Asteraceae	H
B,R,M,A,S	*Ageratum conyzoides* L.	LC	Age con	Asteraceae	H
A	*Ageratum houstonianum* Miller	-	Age hou	Asteraceae	H
R,S	*Alocasia fornicata* (Kunth) Schott	LC	Aloc forn	Araceae	H
B,R,M	*Alysicarpus vaginalis* (L.) DC.	-	Alysi vagi	Fabaceae	H
S	*Anisomeles indica* (L.) Kuntze	-	Anis ind	Lamiaceae	H
M	*Arisaema erubescens* (Wall.) Schott	-	Aris erub	Araceae	H
B	*Arthraxon lancifolius* (Trin.) Hochst.	-	Arthra lanc	Poaceae	H
M,A	*Arundinella nepalensis* Trin.	LC	Arun nep	Poaceae	H
R,S	*Axonopus compressus* (Sw.) P. Beauv.	LC	Axo comp	Poaceae	H
R,A,S	*Barleria cristata* L.	-	Barl cris	Acanthaceae	H
A	*Begonia picta* Sm.	-	Beg pic	Begoniaceae	H
M	*Bidens pilosa* L.	-	Bide pilo	Asteraceae	H
B	*Biophytum sensitivum* (L.) DC.	-	Bio sens	Oxalidaceae	H
B	*Blainvillea acmella* (L.) Philipson	-	Bla acme	Asteraceae	H
M	*Blumea balsamifera* (L.) DC.	LC	Blum balsa	Asteraceae	H
S	*Blumea eriantha* DC.	-	Blum eri	Asteraceae	H
B,M,A,S	*Blumea lacera* (Burm.f.) DC	-	Blum lace	Asteraceae	H
B	*Boerhavia diffusa* L.	-	Boer dif	Nyctaginaceae	H
S	*Cajanu scarabaeoides* (L.) Thouars	-	Caja scar	Fabaceae	H
M,A	*Campylotropis macrostyla* (D. Don) Lindl. Ex Miq.	-	Camp macro	Fabaceae	H
M,S	*Carex elongata* L.	-	Care elon	Cyperaceae	H
R,M	*Carex hirta* L.	-	Care hir	Cyperaceae	H
R	*Carex nubigena* D. Don	-	Care nub	Cyperaceae	H
B,R,M,S	*Centella asiatica* (L.) Urb.	LC	Cen asi	Apiaceae	H
B	*Chrysopogon aciculatus* (Retz.) Trin.	-	Chrys aci	Poaceae	H
M,A	*Chrysopogon zizanioides* (L.) Roberty	-	Chry ziza	Poaceae	H
M,S	*Clematis buchananiana* DC.	-	Clem buch	Rannunculaceae	H
M	*Cocculus laurifolius* DC.	LC	Coc laur	Menispermaceae	H
R,M	*Colocasia esculenta* (L.) Schott	LC	Colo escu	Araceae	H
B,R,M,A	*Commelina benghalensis* L.	LC	Com beng	Commelinaceae	H
S	*Commelina caroliniana* Walter	LC	Com caro	Commelinaceae	H
R	*Commelina suffruticosa* Blume	-	Com suf	Commelinaceae	H
B,A	*Cosmos bipinnatus* Cav.	-	Cos bipi	Asteraceae	H
A,S	*Crassocephalum crepidioides* (Benth.) S. Moore	-	Cras crep	Asteraceae	H

B,R,M,A,S	*Curculigo orchioides* Gaertn.	-	Cur orc	Hypoxidaceae	H
R	*Curcuma angustifolia* Roxb.	-	Cur ang	Zingiberaceae	H
A	*Cyanotis cristata* (L.) D. Don	LC	Cyan cris	Commelinaceae	H
B,A	*Cyanthillium cinereum* (L.) H. Rob.	-	Cyan cin	Asteraceae	H
B,R,M,A,S	*Cynodon dactylon* (L.) Pers.	-	Cyan doct	Poaceae	H
B,R,A,S	*Cyperus brevifolia* Rottb.Hassk	-	Cype brev	Cyperaceae	H
R	*Cyperus difformis* L.	LC	Cyp dif	Cyperaceae	H
R,M	*Cyperus exaltatus* Retz.	LC	Cyp exal	Cyperaceae	H
B	*Cyperus rotundus* L.	LC	Cyp rot	Cyperaceae	H
S	*Dicliptera bupleuroides* Nees .	-	Dicl bup	Acanthaceae	H
M	*Dicliptera chinensis* (L.) Juss.	-	Dicl chin	Acanthaceae	H
B	*Dictyospermum montanum* Wight	-	Dict mon	Commelinaceae	H
B,R,M,A,S	*Digitaria ciliaris* (Retz.) Koeler	-	Digi cil	Poaceae	H
B	*Digitaria setigera* Roth	-	Digi set	Poaceae	H
S	*Dimetia scandens* (Roxb.)R.J.Wang	-	Dime sca	Rubiaceae	H
B,R,M,A,S	*Drymaria diandra* Blume	-	Drym dia	Caryophyllaceae	H
B	*Eclipta prostrata* (L.) L.	-	Ecli pro	Asteraceae	H
S	*Elatostema platyphyllum* Wedd.	-	Ela pla	Urticaceae	H
B,M	*Eleusine indica* (L.) Gaertn.	LC	Eleu ind	Poaceae	H
A,S	*Elsholtzia blanda* (Benth.) Benth.	-	Elsh blan	Lamiaceae	H
	Emilia sonchifolia (L.) DC.	-	Emi son	Asteraceae	H
B,M	*Eragrostis tenella* (L.) P. Beauv.ex Roem. & Schult.	-	Erag tene	Poaceae	H
R	*Erigeron Canadensis L.*	-	Erig can	Asteraceae	H
R,M,A	*Eschenbachia leucantha* (D.Don) Brouillet	-	Esche leu	Asteraceae	H
B,R,S	*Euphorbia hirta* L.	-	Euph hir	Euphorbiaceae	H
B,R	*Evolvulus nummularius* (L.) L.	-	Evol num	Convolvulaceae	H
R	*Floscopa scandens* Lour.	LC	Flos sca	Commelinaceae	H
R,M,A	*Globba clarkei* Baker	-	Glob clar	Zingiberaceae	H
B	*Globba racemosa* Sm.	LC	Glob race	Zigiberaceae	H
B	*Gnaphalium polycaulon* Pers.	LC	Gnaph poly	Asteraceae	H
M,A,S	*Gonostegia hirta* (Blume) Miq.	-	Gono hir	Urticaceae	H
B,S	*Grona triflora* (L.) H. Ohashi & K. Ohashi	-	Gro trif	Fabaceae	H
B	*Hedychium ellipticum* Buch. -Ham. ex Sm.	-	Hedy eli	Zingiberaceae	H
R,M	*Hedychium flavescens* Carey ex Roscoe	-	Hedy flav	Zingiberaceae	H
B	*Hedyotis pruinosa* Wight & Arn.	-	Hed prui	Rubiaceae	H
B	*Hemarthria compressa* (L.f.) R. Br.	LC	Hema com	Poaceae	H
R	*Hydrocotyle sibthorpioides* L.	LC	Hydro sib	Araliaceae	H
B	*Hygrophila auriculata* (Schumach.) Heine	LC	Hygro aur	Acanthaceae	H
B,R,M,A,S	*Imperata cylindrica* (L.) Raeusch.	-	Imp cylin	Poaceae	H
A	*Ipomoea atropurpurea* (Wall.) Choisy	-	Ipo atro	Convolvulaceae	H
S	*Isodon coetsa* (Buch. -Ham. ex D. Don) Kudô	-	Iso coe	Lamiaceae	H
R,A,S	*Koenigia mollis* (D. Don) T. M. Schust. & Reveal	-	Koen mol	Polygonaceae	H

S	*Leucas decemdentata* (Willd.) Sm.	-	Leu dece	Lamiaceae	H
A	*Lindenbergia grandiflora* Benth.	-	Lind gran	Orobanchaceae	H
S	*Mentha canadensis* L.	-	Men cana	Lamiaceae	H
B,M,A,S	*Mikania micrantha* Kunth	-	Mika micra	Asteraceae	H
B,S	*Mimosa pudica* L.	LC	Mimo pud	Fabaceae	H
M	*Murdannia nudiflora* (L.) Brenan	-	Murd nudi	Commelinaceae	H
B,R,M,A,S	*Oplismenus compositus* (L.) P.Beauv.	LC	Opli com	Poaceae	H
B,R,M	*Oplismenus hirtellus* (L.) P. Beauv.	LC	Opli hir	Poaceae	H
R	*Orthosiphon incurvus* Benth.	LC	Orth inc	Lamiaceae	H
B,R	*Oxalis corniculata* L.	LC	Oxa corn	Oxalidaceae	H
R	*Oxalis latifolia* Kunth.	-	Oxa lati	Oxalidaceae	H
B,A	*Paederia* foetida L.	-	Paed foe	Rubiaceae	H
A,S	*Paspalum conjugatum* P.J.Bergius	LC	Pas con	Poaceae	H
M	*Paspalum notatum* Flüggé	-	Pas Nota	Poaceae	H
A	*Peperomia pellucida* (L.) Kunth	-	Pepe pel	Piperaceae	H
S	*Persicaria capitata* (Buch. -Ham. ex D. Don) H. Gross	-	Pers cap	Polygonaceae	H
S	*Persicaria pubescens* (Blume) H. Hara	LC	Pers pub	Polygonaceae	H
A	*Phragmites karka* (Retz.) Trin.ex Steud.	LC	Phrag kar	Poaceae	H
B	*Phyllanthus amarus* Schumach. & Thonn.	-	Phyl ama	Phyllanthaceae	H
B	*Phyllanthus* virgatus G.Forst.	-	Phyl vir	Phyllanthaceae	H
S	*Pilea symmeria* Wedd.	-	Pile sym	Urticaceae	H
B,M	*Piper longum* L.	-	Pip lon	Piperaceae	H
S	*Platostoma hispidum* (L.) A. J. Paton	-	Plat his	Lamiaceae	H
B,M	*Pleurolobus gangeticus* (L.) J.St.-Hil.ex H. Ohashi & Ohashi	-	Pleu gang	Fabaceae	H
R,S	*Pogonatherum crinitum* (Thunb.) Kunth	-	Pogo crin	Poaceae	H
R,S	*Pogostemon amaranthoides* Benth.	-	Pogo ama	Lamiaceae	H
B,R,M,S	*Pogostemon benghalensis* (Burm. f.) Kuntze	-	Pogo ben	Lamiaceae	H
B	*Pouzolzia zeylanica* (L.) Benn.	-	Pouz zey	Urticaceae	H
S	*Pseudognaphalium adnatum* (DC.) Y. S. Chen	-	Pseu ad	Asteraceae	H
R	*Pseudognaphalium affine* (D.Don) Anderb.	-	Pseu aff	Asteraceae	H
B	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L.Burtt	-	Pseud lute	Asteraceae	H
A	*Rhynchoglossum obliquum* Blume	-	Rhyn obli	Gesneriaceae	H
B,M,S	*Rostellularia obtuse* Nees	-	Rost obt	Acanthaceae	H
S	*Rubia manjith* Roxb.	-	Rub man	Rubiaceae	H
R,A,S	*Rungia himalayensis* C.B. Clarke	-	Rung him	Acanthaceae	H
B,M,A	*Rungia pectinata* (L.) Nees	-	Rung pec	Acanthaceae	H
B	*Scoparia dulcis* L.	-	Sco dul	Plantaginaceae	H
B,A	*Scutellaria repens* Buch.- Ham.ex D.Don	-	Scut repe	Lamiaceae	H
S	*Scutellaria scandens* D. Don	-	Scut scan	Lamiaceae	H
M,A,S	*Sida acuta* Burm f.	-	Sida acu	Malvaceae	H
A	*Sida cordata* (Burm. f.) Borss. Waalk.	-	Sida cor	Malvaceae	H
S	*Sida rhombifolia* L.	-	Sida rhom	Malvaceae	H

R	*Smilax aspera* L.	-	Smi asp	Smilacaceae	H
B	*Solanum nigrum* L.	-	Sola nig	Solanaceae	H
R,A	*Solanum virginianum* L.	-	Sola vir	Solanaceae	H
B	*Sonchus asper* (L.) Hill	-	Son asp	Asteraceae	H
S	*Spermacoce alata* Aubl.	-	Sper ala	Rubiaceae	H
B,A	*Spermacoce ocymoides* Burm.f.	-	Sper ocy	Rubiaceae	H
R,M,A,S	*Strobilanthes capitata* (Nees) T. Anderson	-	Strob capi	Acanthaceae	H
R,M,S	*Strobilanthes glutinosa* Nees.	-	Strob glu	Acanthaceae	H
B	*Strobilanthes hirta* (Vahl) Blume	-	Strob hir	Acanthaceae	H
B	*Synedrella nodiflora* (L.) Gaertn.	-	Syne nodi	Asteraceae	H
A	*Synotis cappa* (Buch. -Ham. ex D. Don) C. Jeffrey & Y. L. Chen	-	Syno cap	Asteraceae	H
A,S	*Tetrastigma serrulatum* (Roxb.) Planch.	-	Tetras ser	Vitaceae	H
R,A	*Thunbergia alata* Bojer ex Sims.	-	Thunb ala	Acanthaceae	H
S	*Thyrsanthella sp.*	-	Thyr sp.	Apocynaceae	H
R	*Torenia crustacea* (L.) Cham. & Schltdl.	LC	Tore crus	Linderniaceae	H
B	*Tridax procumbens* L.	-	Trid pro	Asteraceae	H
M,S	*Triumfetta pilosa* Roth	-	Trium Pil	Malvaceae	H
B,S	*Urena lobata* L.	LC	Ure lob	Malvaceae	H
M,S	*Urtica dioica* L.	LC	Urti dio	Urticaceae	H
B	*Veronica javanica* Blume	-	Vero java	Plantaginaceae	H
B,R	*Youngia japonica* (L.) DC.	-	Youn japo	Asteraceae	H
B,R,M,A,S	*Ageratina adenophora (*Spreng.) R. M. King & H. Rob.	-	Age adeno	Asteraceae	S
B,R,S	*Ardisia solanacea* Roxb.	LC	Ardi sola	Myrsinaceae	S
M,A,S	*Artemisia indica* Willd.	-	Arte indi	Asteraceae	S
S	*Barleria strigosa* Willd.	-	Bar strig	Acanthaceae	S
S	*Berberis napaulensis* (DC.) Spring.	-	Berb nep	Berberidaceae	S
B,R,M	*Bergera koenigii* L.	LC	Ber koe	Rutaceae	S
M,S	*Boehmeria ternifolia* D.Don	-	Boeh tern	Urticaceae.	S
S	*Boenninghausenia albiflora* (Hook) Rchb. ex Meisn.	-	Boen alb	Rutaceae	S
R	*Breynia retusa* (Dennst.) Alston	LC	Brey retu	Phyllanthaceae	S
S	*Brugmansia suaveolens* (Humb. &Bonpl. ex Willd.) Sweet	EW	Brug sua	Solanaceae	S
M,A,S	*Butea buteiformis* (Voigt) Grierson	-	Bute bute	Fabaceae	S
B	*Callicarpa macrophylla* Vahl	LC	Calli macro	Lamiaceae	S
R	*Catunaregam spinosa* (Thunb.) Tirveng.[	LC	Cat spin	Rubiaceae	S
A	*Celastrus paniculatus* Wild.	-	Cela pani	Celastraceae	S
S	*Celastrus stylosus* Wall.	-	Cela sty	Celastraceae	S
M,A,S	*Chonemorpha fragrans* (Moon) Alston.	-	Chone frag	Apocynaceae	S
B,R,M,A,S	*Chromolaena odorata* (L.) R. M. King & H. Rob.	-	Chromo odo	Asteraceae	S
R,A,S	*Cipadessa baccifera* (Roxb. Ex Roth) Miq.	LC	Cipa bac	Meliaceae	S
S	*Clerodendrum colebrookianum* Walp.	-	Clero cole	Lamiaceae	S
B,R,M,A,S	*Clerodendrum japonicum (*Thunb.) Sweet	LC	Clero jap	Lamiaceae	S
M,A	*Clerodendrum serratum* Spreng.	-	Clero ser	Lamiaceae	S

B,R,M,A,S	*Clerodrendrum infortunatum* L.	-	Clero inf	Lamiaceae	S
B,R,M,A,S	*Colebrookea oppositifolia* Sm.	LC	Cole opo	Lamiaceae	S
S	*Colquhounia coccinea* Wall.	-	Colq coc	Lamiaceae	S
R,M	*Combretum roxburghii* Spreng.	-	Comb rox	Combretaceae	S
B	*Cyathula prostrata* (L.) Blume	-	Cya pros	Amaranthaceae	S
R	*Debregeasia longifolia* (Burm. f.) Wedd.	LC	Debre long	Urticaceae	S
R	*Desmos chinensis* Lour.	-	Des chin	Annonaceae	S
M,A,S	*Duhaldea cappa* (Buch. -Ham. Ex D. Don) Pruski & Anderb.	-	Dua cap	Asteraceae	S
B,R,M,A,S	*Elaeagnus infundibularis* Momiy.	-	Elaeg inf	Elaeagnaceae	S
M	*Ficus hispida* L.f.	LC	Fic his	Moraceae	S
S	*Flacourtia jangomas* (Lour.) Raeusch.	-	Flac jan	Salicaceae	S
M,A	*Flemingia paniculata Wall*. ex Benth.	-	Flem pani	Fabaceae	S
B	*Flemingia strobilifera* (L.) W. T. Aiton	-	Flem stro	Fabaceae	S
S	*Girardinia diversifolia* (Link) Friis	-	Giru div	Urticaceae	S
S	*Indigofera sp.*	-	Indi sp.	Fabaceae	S
A	*Isodon sp.*	-	Iso sp.	Lamiaceae	S
B	*Jasminum amabile* H. Hara	-	Jasm ama	Oleaceae	S
B,R,M,A,S	*Justicia adhatoda* L.	LC	Just adha	Acanthaceae	S
R,M	*Laggera alata* S.Moore	-	Lag ala	Asteraceae	S
B,R,M,A,S	*Lantana camara* L.	-	Lant cam	Verbenaceae	S
B,S	*Leea indica* (Burm. f.) Merr.	LC	Leea ind	Vitaceae	S
R,M,A	*Leea macrophylla* Roxb. ex Hornem.	-	Leea macr	Vitaceae	S
R,M,A	*Leucomeris spectabilis* D.Don	-	Leu spec	Asteraceae	S
B	*Litsea salicifolia* (Roxb. ex Nees) Hook. f.	LC	Lits Sali	Lauraceae	S
B,R,M,A,S	*Maesa chisia* D. Don.	-	Maesa chi	Primulaceae syn. Myrsinaceae	S
R,M,A,S	*Maesa macrophylla* (Wall.) A. DC.	-	Maesa mac	Primulaceae	S
M	*Martynia annua* L.	-	Mart an	Martyniaceae	S
B,A,S	*Melastoma malabathricum* L.	-	Melas mala	Melastomataceae	S
M,A	*Millettia extensa* (Benth.) Benth. ex Baker	-	Mile ext	Fabaceae	S
R	*Mussaenda macrophylla* Wall.	-	Mussa macro	Rubiaceae	S
A	*Nyctanthes arbor-tristis* L.	LC	Nyct arb	Oleaceae	S
M,S	*Osbeckia stellata* Buch. -Ham. ex D.Don	-	Osbe ste	Melastomataceae	S
B, A	*Ototropis conferta* (DC.) H. Ohashi & K. Ohashi	-	Oto con	Fabaceae	S
R	*Paramignya monophylla* Wight	-	Para mono	Rutaceae	S
S	*Phyllanthus clarkei* Hook.f.	-	Phyl cla	Phyllanthaceae	S
A,S	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P. D. Cantino	-	Pseu bi	Lamiaceae	S
B	*Rauvolfia serpentina* (L.) Benth. ex Kurz.	LC, Appd.II	Rau ser	Apocynaceae	S
S	*Reinwardtia indica* Dumort.	-	Rein ind	Linaceae	S
M	*Rotheca serrata* (L.) Steane & Mabb.	-	Roth ser	Lamiaceae	S
A,S	*Rubus ellipticus* Sm.	LC	Rubu elli	Rosaceae	S
S	*Sambucus javanica subsp. Chinensis* (Lindl.) Fukuoka	LC	Sam java	Adoxaceae	S
S	*Sarcococca coriacea* (Hook.) Sweet	-	Sar cori	Buxaceae	S

R,S	*Solanum viarum* Dunal	-	Sol via	Solanaceae	S
A,S	*Spermadictyon suaveolens* Roxb.	-	Sperm sua	Rubiaceae	S
A	*Thalictrum punduanum* Wall.	-	Thalic pun	Ranunculaceae	S
M,A,S	*Thysanolaena latifolia* (Roxb.ex Hoenem.) Honda	-	Thysa lat	Poaceae	S
R,S	*Uncaria sessilifructus* Roxb.	-	Unc sessi	Rubiaceae	S
A,S	*Woodfordia fruticosa* (L.) Kurz	LC	Woodf fruc	Lythraceae	S
B,R,M,S	*Acer oblongum* Wall. ex DC.	LC	Acer obl	Sapindaceae	T
M,A,S	*Actinodaphne lanceolata* Daizell & A.Gibson.	DD	Acti lan	Lauraceae	T
B,R,M,A	*Adina cordifolia* (Roxb.) Brandis	LC	Adi cor	Rubiaceae	T
B	*Aegle marmelos* (L.) Correa	NT	Aegl marm	Rutaceae	T
B,R,M	*Alangium salviifolium* (L.f.) Wangerin	LC	Alan salv	Cornaceae	T
B,R	*Albizia lebbeck* (L.) Benth.	LC	Alb leb	Fabaceae	T
B, R, A, S	*Albizia julibrissin* Durazz.	VU	Alb jul	Fabaceae	T
S	*Albizia lucidor* (Steud.) I. Neielsen ex H. Hara	-	Alb luc	Fabaceae	T
B,M,A,S	*Albizia procera* (Roxb.) benith.	Lc	Alb pro	Fabaceae	T
R,M,S	*Alnus nepalensis* D. Don	LC	Aln nep	Betulaceae	T
B,R,A	*Alstonia scholaris* (L.) R. Br.	LC	Als sch	Apocynaceae	T
R	*Aporosa octandra* (Buch. -Ham. ex D.Don) Vickery	LC	Apo oct	Phyllanthaceae	T
B	*Bauhinia malabarica* Roxb.	LC	Bauh mala	Fabaceae	T
B,S	*Bombax ceiba* L.	LC	Bomb ceib	Malvaceae	T
B,M,S	*Bridelia retusa* (L.) A. Juss.	LC	Brid retu	Euphorbiaceae	T
S	*Brucea javanica* (L.) Merr.	LC	Bru java	Simaroubaceae	T
R,M,A,S	*Callicarpa arborea* Roxb.	LC	Calli arb	Lamiaceae	T
B,R,M	*Careya arborea* Roxb.	-	Car arb	Lecythidaceae	T
R	*Caryota urens* L.	LC	Cary ure	Arecaceae	T
B,R,M,A	*Casearia graveolens* Dalzell	-	Case grav	Salicaceae	T
B,R	*Cassia fistula* L.	LC	Cas fis	Fabaceae	T
R,M,A,S	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	LC	Cast indi	Fagaceae	T
A,S	*Castanopsis tribuloides* (Sm.) A. DC.	LC	Cast trib	Fagaceae	T
S	*Cinnamomum tamala* (Buch-Ham.) T. Nees & C.H.Eberm.	LC	Cinna tam	Lauraceae	T
B,R,M	*Cornus oblonga* Wall.	LC	Cor obl	Cornaceae	T
B,R	*Croton persimilis* Mull.Arg.	LC	Crot per	Euphorbiaceae	T
B,R,M,A	*Dalbergia latifolia* Roxb.	VU, Appd.II	Dal lat	Fabaceae	T
B	*Dalbergia sissoo* Roxb.	LC, Appd.II	Dal sis	Fabaceae	T
R,M,A	*Dalbergia stipulacea* Roxb.	LC	Dal sti	Fabaceae	T
B,R,M,A	*Dillenia pentagyna* Roxb.	-	Dil pen	Dilleniaceae	T
B,R,A	*Diospyros chloroxylon* Roxb.	-	Dios chlo	Ebenaceae	T
M	*Diospyros montana* Roxb.	-	Dios mon	Ebenaceae	T
B,M,A	*Diploknema butyracea* (Roxb.) H. J. Lam	-	Dipl but	Sapotaceae	T
R	*Docynia indica* (Colebr.ex Wall.) Decne.	-	Doc ind	Rosaceae	T
R,M,S	*Duabanga grandiflora* (Roxb. ex DC.) Walp	LC	Dua gran	Lythraceae	T
B,R,A	Ehretia acuminata (DC.) R. Br.	LC	Ehre acu	Boraginaceae	T

A	*Elaeodendron glaucum* (Rottb.) Pers.	DD	Elae glau	Celastraceae	T
M,A,S	*Engelhardia spicata* Lechen ex Blume	LC	Enge spi	Juglandaceae	T
S	*Erythrina stricta* Roxb. ·	-	Ery stric	Fabaceae	T
S	*Eurya acuminata* DC.	LC	Eur acu	Pentaphylacaceae	T
B,M,A,S	*Falconeria insignis* Royle	-	Fal ins	Euphorbiaceae	T
B	*Ficus lacor* Buch.-Ham.	-	Fic lac	Moraceae	T
S	*Ficus neriifolia* Sm.	-	Fic ner	Moraceae	T
B	*Ficus racemosa* L.	LC	Fic race	Moraceae	T
B,M,S	*Ficus semicordata* Buch. -Ham. ex Sm.	LC	Fic semi	Moraceae	T
S	*Firmiana colorata* (Roxb.) R. Br.	LC	Firm col	Malvaceae	T
B,R,M	*Garuga pinnata* Roxb.	-	Garu pin	Burseraceae	T
B,M	*Gmelina arborea* Roxb.ex Sm.	LC	Gme arb	Lamiaceae	T
B,M,S	*Grewia optiva* J. R. Drumm. ex Burret	LC	Grew opt	Malvaceae	T
S	*Gynocardia odorata* R.Br.	-	Gyno odo	Achariaceae	T
B,R,M	*Heynea trijuga* Roxb.ex Sims	LC	Hey tri	Meliaceae	T
B,R	*Holarrhena pubescens* Wall. ex G. Don.	LC	Hola pub	Apocynaceae	T
B	*Holoptelea integrifolia* (Roxb.) Planch.	LC	Holo inte	Ulmaceae	T
R,S	*Homalium napaulense (*DC) Benth.	-	Homa nap	Salicaceae	T
R	*Knema tenuinervia* W. J. de Wilde	-	Kne ter	Myristicaceae	T
B,R,A	*Lagerstroemia parviflora* Roxb.	LC	Lager par	Lythraceae	T
B,A	*Lannea coromandelica* (Houtt.) Merr.	LC	Lan coro	Anacardiaceae	T
S	*Leucosceptrum canum* Sm.	-	leuco can	Lamiaceae	T
A	*Ligustrum robustum* (Roxb.) Blume	LC	Ligus robus	Oleaceae	T
R,M,A,S	*Litsea monopetala* (Roxb.) pers.	LC	Lits mono	Lauraceae	T
R,M,A,S	*Macaranga indica* Wight	LC	Maca ind	Euphorbiaceae	T
B,R	*Mallotus nudiflorus* (L.) Kulju & Welzen	LC	Malo nudi	Euphorbiaceae	T
B,R,M,A,S	*Mallotus philippensis* (Lam.) Müll.Arg.	LC	malo phi	Euphorbiaceae	T
M,S	*Micromelum integerrimum* (Roxb. ex DC.) Wight & Arn. ex Voigt	LC	Micro inte	Rutaceae	T
B,M	*Miliusa velutina* (DC) Hook.f. &Thomson	LC	Mili vel	Annonaceae	T
B	*Neolamarckia cadamba (*Roxb.) Bosser	-	Neo cad	Rubiaceae	T
R,M,A	*Neolitsea cuipala* (D. Don) Kosterm.	LC	Neol cui	Lauraceae	T
S	*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & S.H.Oh	LC	Notho den	Fagaceae	T
B,A	*Oroxylum indicum (*L.) Kurz	LC	Oro ind	Bignoniaceae	T
S	*Ostodes paniculata* Blume	LC	Osto pani	Euphorbiaceae	T
B	*Ougeinia oojeninensis* {Roxb.) Hochr.	-	Oug ooj	Fabaceae	T
B,R,M,A	*Phanera vahlii* (Wight &Arn.) Benth.	-	Phan vah	Fabaceae	T
B,R,M,A	*Phyllanthus emblica* L.	LC	Phyl emb	Phyllanthaceae	T
A	*Pouzolzia rugulosa* (Wedd.) Acharya & Kravtsova	-	Pouz rugu	Urticaceae	T
B	*Prasoxylon excelsum* (Spreng.) Mabb.[	LC	Dyso ex	Meliaceae	T
B	*Premna mollissima* Roth	-	Prem mol	Verbenaceae	T
R	*Pterospermum acerifolium* (L.) Willd.	LC	Pter ace	Malvaceae	T
A,S	*Saurauia napaulensis* DC.	LC	sau napa	Actinidiaceae	T

R,M,A,S	*Schima wallichii (*DC.) Korth.	LC	Schi wal	Theaceae	T
B,M	*Schleichera oleosa* (Lour.) Oken	LC	Sche ole	Sapindaceae	T
B,R,M,A	*Semecarpus anacardium* L.f.	LC	Seme ana	Anacardiaceae	T
B	*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb.	LC	Sene cate	Fabaceae	T
M	*Senegalia intsia* (L.) Maslin, Seigler & Ebinger	LC	Sene ins	Fabaceae	T
B,R,M,A	*Shorea robusta* C.F. Gaertn.	LC	Shor robu	Dipterocarpaceae	T
B	*Spondias pinnata* (L.f.) Kurz	-	Spon pin	Anacardiaceae	T
B,R,A	*Sterculia villosa* Roxb.ex Sm.	LC	Sterc vil	Malvaceae	T
B	*Streblus asper* Lour.	LC	Stre asp	Moraceae	T
B,R,M,A,S	*Syzygium cumini* (L.) Skeels	LC	Syzy cum	Myrtaceae	T
B,R	*Syzygium nervosum* A. Cunn. ex DC.	LC	Syzy ner	Myrtaceae	T
B	*Tamarindus indica* L.	LC	Tama ind	Fabaceae	T
B,R,M,A	*Terminalia alata* Heyne ex Roth.	LC	Term ala	Combretaceae	T
B,R,M	*Terminalia bellirica* (Gaertn.) Roxb.	LC	Term bel	Combretaceae	T
B,R,M,S	*Terminalia chebula* Retz.	LC	Term che	Combretaceae	T
M	*Terminalia myriocarpa* Van Heurck & Müll.Arg.	-	Term myri	Combretaceae	T
M,A,S	*Tetradium fraxinifolium* (Hook.) T.G. Hartley	LC	Tetra frax	Rutaceae	T
R	*Tetrameles nudiflora* R. Br.	LC	Tetra nudi	Tetramelaceae	T
R,M,A	*Toona ciliata* M. Roem.	LC	Toon cil	Meliaceae	T
R,M,A,S	*Toxicodendron succedaneum* (L.) Kuntze	LC	Toxi succ	Anacardiaceae	T
B	*Trema orientalis* (L.) Blume.	LC	Trem ori	Cannabaceae	T
R,M,A	*Wendlandia heynei (Schult.) Santapau & Merchant*	LC	Wend hey	Rubiaceae	T
M,A,S	*Wrightia arborea* (Dennst.) Mabberly	LC	Writ arb	Apocynaceae	T
R,A,S	*Zanthoxylum armatum* DC.	LC	Zanth arma	Rutaceae	T
B	*Zizyphus jujuba* Mill.	-	Zizy juju	Rhamnaceae	T

Note: A: Adheri forest, B: Bhaunne forest, M: Murchungi forest, R: Raja-Rani forest, S: Sagma forest, DD: data deficient, EW: Extict in the Wild, VU: Vulnerable, LC: Least concern, Appd.II: CITES- Appendix II.

Appendix II.

A. List of publications

A.1 Plant biomass and carbon stocks in different forests along varied elevation of eastern Nepal in ***Journal of Banko Jankari***

A.2 Gachhadar, P.K., Mandal, T.N., Chaudhary, R.P. & Baniya, C.B. (2023). Plants used in medicinal practices by the tribal people of Morang District in Koshi Province of Nepal. ***Pleione***, 17(2): 117 - 137. doi:10.26679/Pleione.17.2.2023.163-190.

A.3 Gachhadar, P.K., Mandal, T.N., & Baniya, C.B. (2023). Forest structure and biodiversity patterns along elevational gradients in Eastern Nepal. ***Scientific World***, 16(16): 106-127.

A.4 Gachhadar, P.K., Mandal, T.N., & Baniya, C.B. (2022). Soil organic carbon stocks in the forests of different continents. ***Our Nature***, 20(1): 57-69. DOI: https://doi.org/10.3126/on.v20i1.45219.

https://doi.org/10.3126/banko.v34i1.62716 Banko Janakari, Vol 34 No. 1, 2024 Pp 15–29

Pattern of plant biomass and carbon stock along different elevational forests in eastern Nepal

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The primary aim of this investigation was to determine the biomass and carbon stock distribution pattern among different forest stands of diverse elevations in the Morang district of East Nepal. It is noteworthy to estimate carbon stock and biomass of relatively least underexplored forests in east Nepal. The data for estimating the biomass and carbon stocks of the five different forest sites, viz. Bhaunne, Raja-Rani, Murchungi, Adheri, and Sagma located between 100–1300m above the mean sea level, were acquired through the measurement of inventory plots selected randomly. Altogether, 50 sample plots were established within five forest stands located on different elevational zone; within each forest site, 10 sample plots of 20m × 20m size, were laid out for the measurement of trees. In the case of shrubs and herbs, nested plots of 5m × 5m and 1m ×1m, respectively were established. Calculation of the biomass of trees and shrubs was facilitated through the application of an allometric equation, while the biomass of herbs was determined by the harvest method. The carbon concentration in the plant materials was estimated using ash content method. The comprehensive analysis of the stand biomass in the Bhaunne, Raja-Rani, Murchungi, Adheri, and Sagma forest sites were: 815.86 Mg ha^{-1}, 414.19 Mg ha^{-1}, 606.81 Mg ha^{-1}, 519.20 Mg ha^{-1}, and 299.96 Mg ha^{-1}, respectively, with minimum at the Sagma site (high-altitude forest) and maximum at the Bhaunne site (low-altitude forest). As per the variation in stand biomass, the carbon stocks in the forest sites also showed the same trend, but the values ranged from 140.19 Mg C ha^{-1} to 333.63 Mg C ha^{-1}, with the minimum in the Sagma site and the maximum in the Bhaunne site. The application of the Friedman Test revealed statistically significant variation in the tree biomass between the Murchungi and Sagma sites and also in the shrub biomass between the Adheri and Sagma sites. Similarly, noteworthy variations were observed in the herb biomass of the Bhaunne, Raja-Rani, Murchungi, and Adheri sites as compared to that of the Sagma site. The present study contributes to the understanding of forest ecosystems in context to carbon management.

Key words: Biomass, Carbon Stocks, Morang district, Tropical forest.

Forests play a significant role in supporting human livelihoods, ensuring the provision of clean air and water, safeguarding biodiversity and mitigating the adverse effects of climate change (Aerts & Honnay, 2011). The impact of forests on the global carbon cycle is now well acknowledged since forests and their soils are significant atmospheric carbon sinks (Basu, 2009). Further, forests, as pivotal components of the global carbon cycle, play a multifaceted

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role in sequestering atmospheric carbon through accumulation of biomass and soil organic carbon. The concept of biomass in the context of forests encompasses the captured or stored carbon within trees, consisting a vital component of the terrestrial ecosystem's carbon pools. These pools comprise aboveground biomass, belowground biomass, litter, woody debris, and soil organic matter, as they are also identified by the Intergovernmental Panel on Climate Change (IPCC) as the main carbon pool (Vashum & Jayakumar, 2012; IPCC, 2013; IPCC, 2023). Forests contribute to 34% of the terrestrial gross primary production and serve as reservoir of approximately 55% of the world's forest carbon (Beer *et al.*, 2010; Pan *et al*., 2011; Hassan *et al*., 2020).

Forests located along elevational gradients exhibit variation in plant species composition, density, biomass and carbon stock which garner a significant attention in the realm of environmental research. Carbon stock in a forest is a complex process, intricately linked to various factors such as seasons, vegetation types, climate, soil structure, and nutrient availability (Chave *et al*., 2005). This complex phenomenon underscores the need for a comprehensive understanding of the dynamics of carbon sequestration in forest ecosystems, particularly in the context of elevation gradients.

Despite the importance of forests in biomass production and carbon sequestration, the works in this regard is limited, especially in the tropical forests of Nepal (Mandal, 1999; Baral *et al*., 2009). Thus, there exists a compelling need to deepen our understanding of forest composition and function, particularly in the context of elevation gradients. Hence, the present study is designed to achieve the objective of assessing the plant biomass and carbon stocks of different forests at varying elevations in east Nepal.

Materials and methods

Study area

The study was conducted across five different forest sites, viz. Bhaunne (within Belbari-Chisang Cooperative Forest, Raja-Rani (within Raja-Rani Community Forest (CF), Murchungi (within Akashe CF), Adheri (within Shat-Kanya CF), and Sagma (within Kuwapani CF) in Morang district, east Nepal (Figure 1). The sites were located between 26°39'45.69"–26°48'28.68"N latitudes and between 87°28'2.08"–87°28'45.06"E longitudes, with the terrain ranging from 100 m to 1300 m above the mean sea level (msl).

Geology and soil

The study area lies in the Churia hills composed of mostly soft limestone and the Mahabharat range made of Phyllite, Schist, Quartzite, limestone, etc. The soils of all the study sites except the Sagma site are, moreover, loamy sand; the soils of the Sagma site being sandy loam.

Climate

The district experiences a diverse types of climate, ranging from tropical to temperate. The southern part of the district exhibits tropical and subtropical types of climate while there is temperate type of climate in the northern part. There is a tropical monsoon climate with dry and warm summer, wet and warm rainy season, and dry and cool winter in areas up to 1000 m above sea level. The mean annual minimum temperature ranges from 11°C to 25°C. while mean annual maximum temperature ranges from 21°C to 35°C (DHM, 2022). Comparatively, the Bhaunne to Murchungi forest area experiences its greatest annual rainfall, which ranges from 64.4 mm to 10630.12 mm (Figure 2a). In Adheri and Sagma sites, the cold season generally begins from the beginning of December and lasts till the end of February, with temperatures dropping to around 7°C. The annual rainfall ranges from 27.9 mm to 4908.6 mm, peaking in July and reaching a minimum in November (DHM, 2022). The annual minimum temperature ranges from 7°C to 21°C while the annual maximum temperature ranges from 20°C to 30°C (Figure 2b).

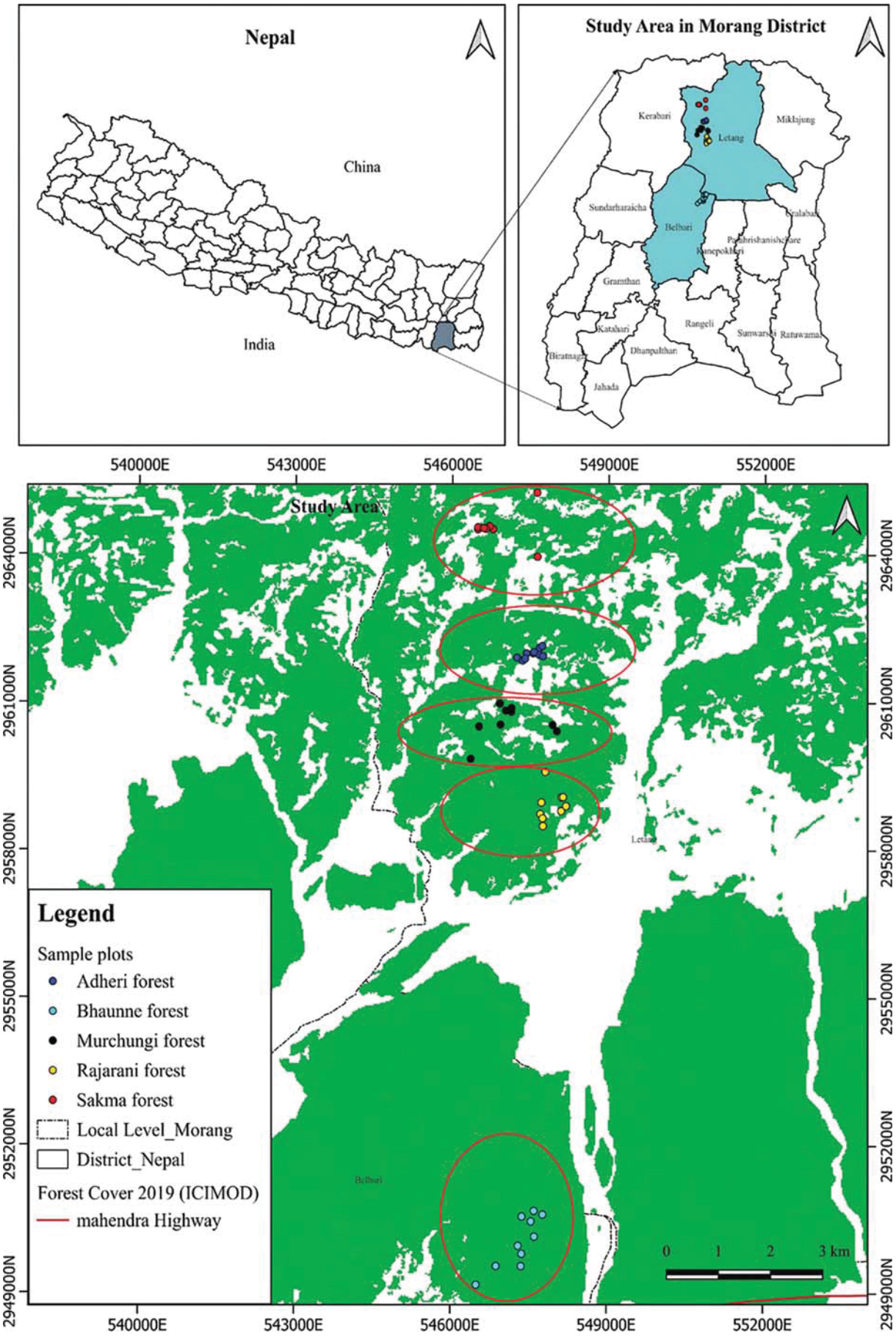

Figure 1: Map of the study area showing the layout and sampling plots.

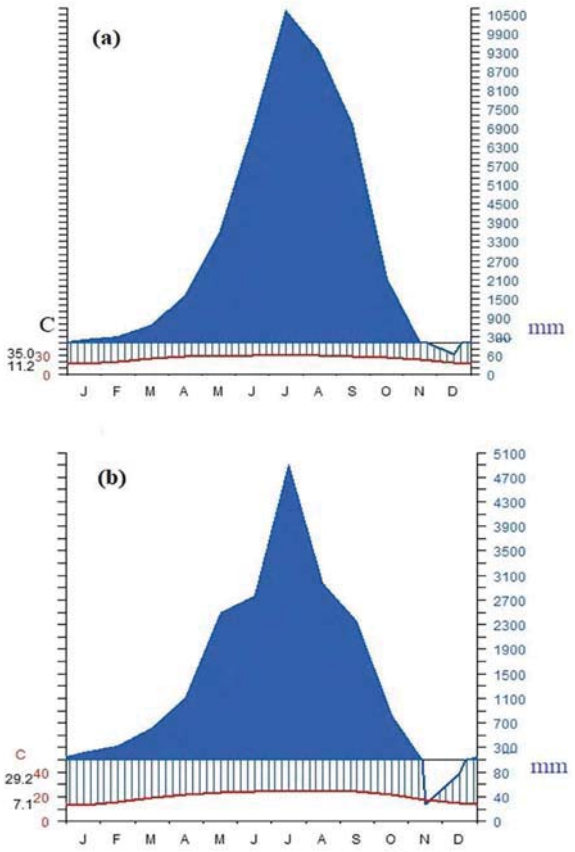

Fig. 2 (a, b): Ombrothermic representation of the climate in the study area; data belonging to the period 2000–2020 *(Source: DHM, 2022).*

Plant biomass estimation

The estimation of plant biomass involved various steps across the five forest stands. For the estimation of tree biomass, a total of 50 permanent sample plots (20m × 20m), with 10 in each stand, were established randomly. Similarly, for the estimation of shrub biomass, 5m × 5m sized nested quadrats were laid out, and for the estimation of herb biomass, 1m × 1m sized nested quadrats were established in each permanent tree plot. The girth of all standing trees with girths more than 10 cm GBH i.e. girth at breast height (1.37 m) were measured. Similarly, girth of shrubs inside the plots were measured at 10 cm above the ground. Utilizing the girth: biomass allometric equation developed by Singh & Singh (1992) for the Sal (*Shorea robusta*) forest of the Siwalik region, the biomass (aboveground biomass) of the trees with girths greater than 30 cm was determined for each plot. In this case, the major root-biomass was estimated by using the root to shoot ratio developed by Singh (1974) for Sal forest. In the case of the estimation of the aboveground and belowground biomass of Sal trees having 10–30 cm girth and also for shrubs, another set of girth: biomass regression equations developed by Mandal (1999) for the forest of eastern Siwaliks of Nepal were used. The aboveground biomass of herbs within the sampling plots was estimated using destructive sampling, i.e. by cutting and weighing all the herbs within the nested plots set aside for the measurement of herbs.

The fine-roots (<5 mm diameter, may be of herbs, shrubs and trees) in soil monoliths (10cm × 10cm × 30cm) were collected from 50 sample plots, with 10 sample plots within each site. The fine-root biomass (FRB) was estimated by washing the soil monolith with fine jet of waters. Within each sample plot, the depth ranges were separated into upper (0–15 cm) and lower (15–30 cm).

Estimation of carbon in vegetation

The samples of trees, shrubs and herbs (aboveground) components were collected within each sampling plot for carbon estimation. Additionally, fine-root samples (<2mm and 2–5mm diameter) were collected and weighed. Composite samples of all components were subjected to oven drying at 80 °C until a constant weight was achieved, followed by powdering of each component for carbon (C) analyses. The ash-free weight method was used to estimate the carbon concentration (McBrayer & Cromack, 1980).

With this technique, each oven-dried plant part (stem, branch, twig, root, and leaf) was burned separately at 400 °C in an electric furnace. After burning, resulting ash content; the inorganic elements in the form of oxides, was weighed. The carbon concentration was then calculated using the following equation:

Carbon % = (Initial weight – Ash weight) × 100/2

Carbon stock in vegetation was calculated by multiplying the dry weight biomass by the C-concentration.

Statistical analysis

Initially, the observed data underwent testing for normality distribution. The carbon stock and biomass data were identified as quantitative variables while forest types were used as categorical variables. An equal number of samples were collected from each forest. However, the data exhibited unequal variance and non-normal distribution. Consequently, a non-parametric alternative to one-way analysis of variance (ANOVA), specifically the Friedman Test was used to assess the distribution of medians among the forest stands. After statistically significant results obtained by using the Dunn Test (Dunn, 1964), multiple pairwise comparisons were conducted through the Friedman Test; it was also referred to as the 'Sign Test' when p-adjustments were made through the Bonferroni test. In this test, fixed errors caused by sampling biases among the sample plots were corrected after partialling out from random errors caused by forests.

The Friedman Test was used by using the formula:
friedman_test(data, a ~ b|c)

In this formula, 'data' refers to data.frame containing variables such as 'fine.root.biomass', as well as 'Forests', 'Plots' etc. The variable 'a' represents the response variable, for instance, 'fine.root.biomass'. 'b' denotes the predictor variable, which is 'Forest' in this context. 'c' stands for the fixed variable, represented here by 'Plots'.

All the analyses were conducted using the R Software (R Core Team, 2023).

Results

Plant biomass and carbon stock

The total biomass estimation revealed that the Bhaunne forest possessed the highest stock of biomass (815.86 Mg·ha^{-1}) and carbon (333.63 Mg C·ha^{-1}) while the Sagma forest had the lowest biomass stock of 299.96 Mg·ha^{-1} and carbon stock of 140.19 Mg C·ha^{-1} (Table 1). The total biomass and carbon stocks of tree layer were found to be the highest in the Bhaunne forest, with 796.46 Mg·ha^{-1} and 326.91 Mg C·ha^{-1}, respectively while the lowest was in the Sagma forest, with 265.23 Mg·ha^{-1} and 124.88 Mg C·ha^{-1}, respectively (Table 2 and Annex-I).

Across all the forest stands, it was observed that 79% of the total tree biomass belonged to aboveground while the remaining 21% being belowground (excluding fine-roots). The boles (main trunks) of the trees contributed the highest proportion to the total stand biomass in in all the study sites; however, the proportions of their contribution decreased with the increase in elevation, with the maximum (514.29 Mg·ha^{-1}) at Bhaunne site and the minimum (154.33 Mg C·ha^{-1}) at Sagma site. Additionally, the Sagma site possessed the highest shrub biomass of 16.38 Mg·ha^{-1} which decreased with the increase in elevation. Likewise, the aboveground herb biomass was maximum (8.65 Mg·ha^{-1}) in the Sagma site. The aboveground biomass and carbon stock showed almost decreasing pattern with the increase in elevation (Figure 3).

Table 1: Oven dry stand biomass (Mg ha $^{-1}$ ± SE) of forests located at different elevation in Morang district

Forest stands / Components		Bhaunne	Raja-Rani	Murchungi	Adheri	Sagma
Tree	Bole	514.29 ± 167.50	230.02 ± 38.15	336.93 ± 44.27	286.04 ± 36.69	154.33 ± 42.15
	Branch	70.16 ± 7.35	46.69 ± 7.01	73.44 ± 7.51	66.10 ± 6.60	38.37 ± 8.14
	Twig	30.67 ± 6.30	17.89 ± 2.78	28.06 ± 3.16	26.27 ± 2.71	10.51 ± 1.57
	Leaf	16.99 ± 1.74	11.41 ± 1.59	17.37 ± 1.86	17.92 ± 1.47	7.29 ± 1.16
	Course root	164.35 ± 45.13	79.56 ± 12.84	118.51 ± 14.7	103.05 ± 12.31	54.73 ± 13.35
	Total	**796.46 ± 218.72**	**385.57 ± 62.23**	**574.31 ± 71.23**	**499.38 ± 59.64**	**265.23 ± 64.72**
Shrub	Stem	3.79 ± 0.60	7.17 ± 1.05	7.29 ± 1.90	4.15 ± 0.70	8.58 ± 1.10
	Leaf	1.50 ± 0.18	2.07 ± 0.25	2.01 ± 0.30	1.70 ± 0.18	3.01 ± 0.18
	Root	3.24 ± 0.6	4.61 ± 0.50	5.11 ± 1.33	2.63 ± 0.33	4.79 ± 0.55
	Total	**8.53 ± 1.21**	**13.85 ± 1.79**	**14.41 ± 3.5**	**8.48 ± 1.14**	**16.38 ± 1.76**
Herbs*		3.73±3.35	2.04±1.85	2.09 ±1.89	1.80 ± 1.52	8.65 ±7.73
Fine-root		7.14± 0.84	12.73 ± 1.43	16.00 ± 2.69	9.54 ± 0.83	9.70 ± 1.42
Total stand vegetation		**815.86**	**414.19**	**606.81**	**519.20**	**299.96**

*Aboveground part

Table 2: Component wise Carbon stock (Mg C·ha^{-1}) estimates in different growth forms in different forests of Morang district

GROWTH - FORM	COMPONENT	FOREST STANDS				
		BHAUNNE	RAJA-RANI	MURCHUNGI	ADHERI	SAGMA
TREE	BOLE	207.39	103.89	157.80	82.00	72.54
	BRANCH	30.63	22.72	34.15	26.55	18.35
	TWIG	14.77	7.93	13.28	11.04	5.06
	LEAF	6.66	5.27	8.08	7.53	3.16
	COURSE ROOT	67.46	36.35	55.46	33.05	25.77
	TOTAL	**326.91**	**176.16**	**268.77**	**160.17**	**124.88**
SHRUB	STEM	1.74	3.31	3.50	1.73	4.08
	LEAF	0.66	0.96	0.95	0.76	1.40
	ROOT	0.24	1.36	2.33	1.03	2.23
	TOTAL	**2.64**	**5.63**	**6.78**	**3.52**	**7.71**
HERB		1.18	0.60	0.57	0.77	3.70
FINE-ROOT		2.90	4.10	7.00	4.20	3.90
TOTAL		**333.63**	**186.49**	**283.12**	**168.66**	**140.19**

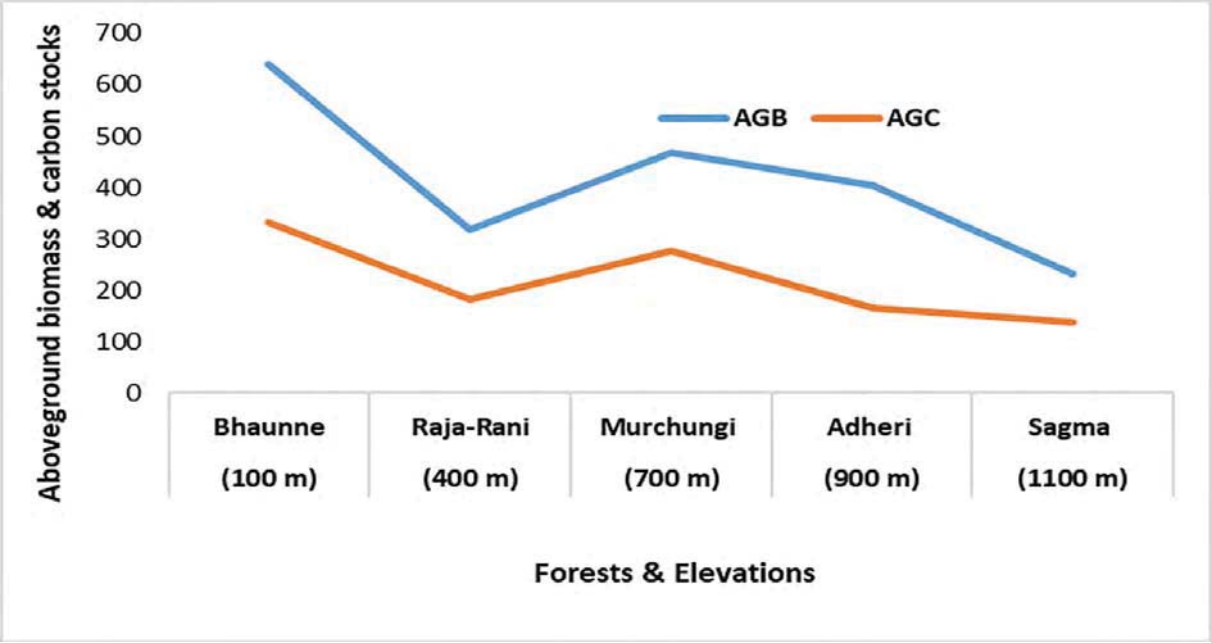

Fig. 3: Trend of aboveground biomass (Mg ha^{-1}) and carbon stock (MgCha^{-1}) in the forests located at different elevations of Morang district.

Fine-root biomass and carbon stock

The total fine-root biomass and carbon stock exhibited the maximum values of 16 Mg ha^{-1} and 7 Mg C ha^{-1}, respectively in the Murchungi site located in the mid-mountain region and the minimum values of 7.14 Mg ha^{-1} and 2.90 Mg C ha^{-1}, respectively in the Bhaunne site (low-elevation site, Figure 4).

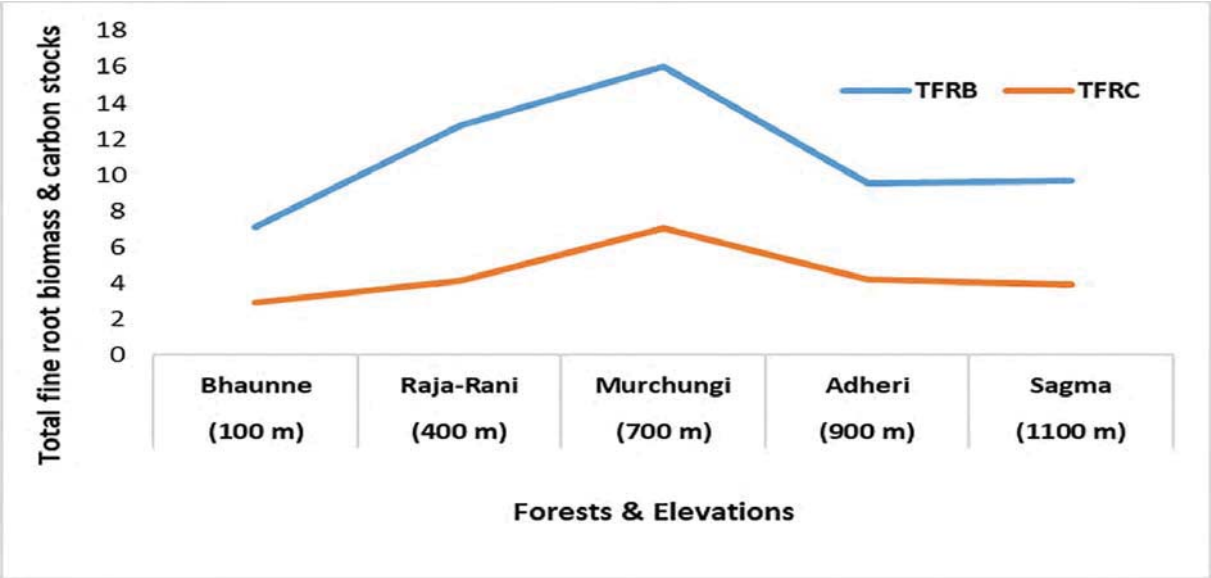

Figure 4: Trend of total fine-root biomass (Mgha^{-1}) in the forests located at different elevations of Morang district.

The maximum fine-root biomass value was recorded in the Murchungi site in terms of both soil depths and fine-root size classes (<2mm and 2–5mm), where the total maximum fine-root biomass was 9.63 Mg ha^{-1} within the 0–15cm soil depth and reaching up to 6.37 Mg ha^{-1} within the 15–30cm soil depth (Figure 5).

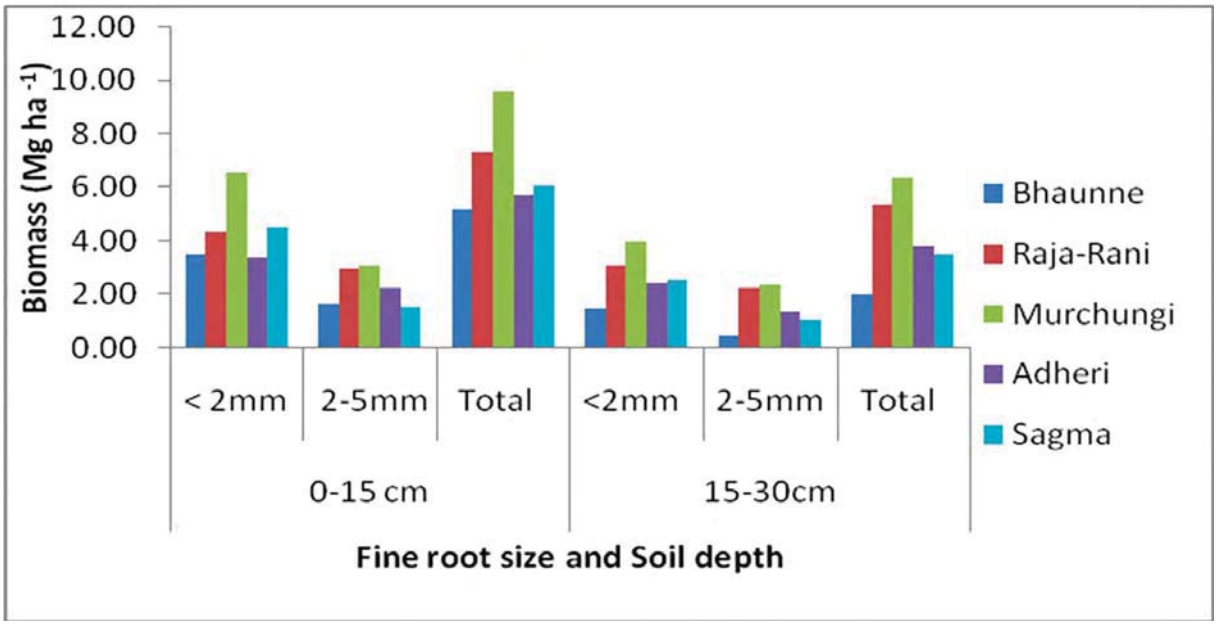

Figure 5: Fine-root biomass at 0–15 cm and 15–30 cm soil depth of different sites.

The carbon stock value was also maximum (5.44 Mg ha^{-1}) for both <2mm and 2–5mm diameter classes in 0-30 cm soil depth (Figure 6). The fine-root biomass was not found to be statistically significant among the studied forest sites even in the case of both diameter classes (<2mm and 2–5mm).

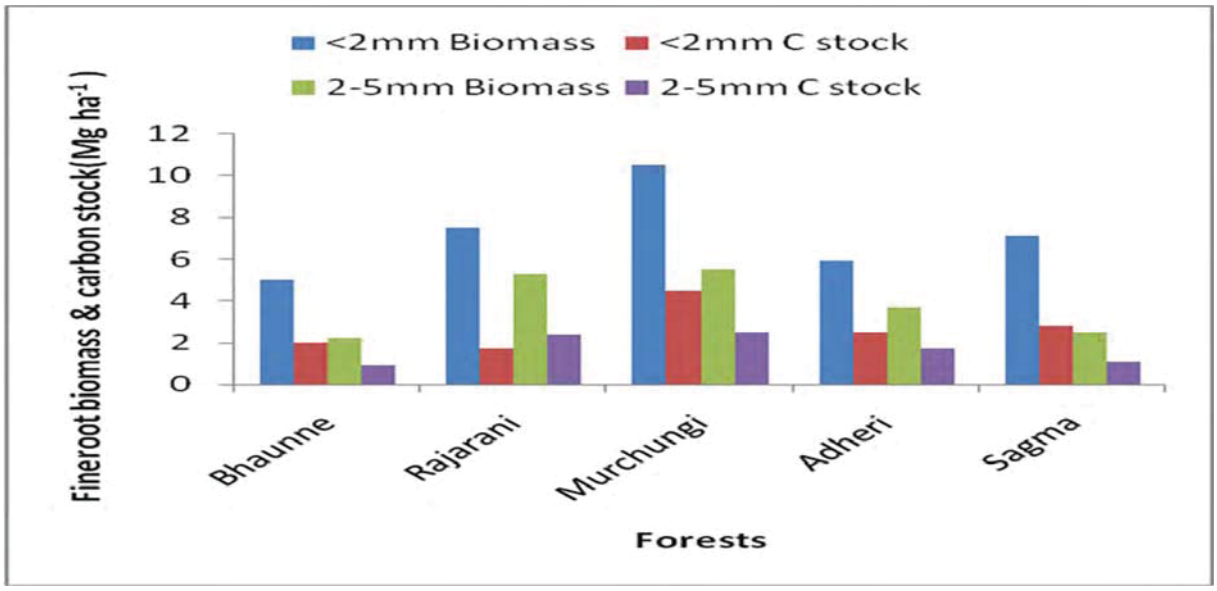

Figure 6: Fine-root biomass and carbon stocks (Mg C·ha^{-1}) of <2mm and 2–5mm diameter classes within 0–30cm soil depth.

Friedman Test

The Friedman Test conducted on three variables (trees, shrubs, and herbs biomass) revealed distinctive differences in the distribution of tree biomass among the five different forests. Statistical significant disparities were noted in the tree biomass between the Murchungi and Sagma sites (p=0.021, Figure 7). Regarding the shrub biomass, statistical significant differences were observed between the Adheri and Sagma sites (p=0.017, Figure 8). Moreover, statistical significant differences in the herb biomass were observed among the Bhaunne and Sagma, Raja-Rani and Sagma, Murchungi and Sagma, and Adheri and Sagma sites (p=0.0001, Figure 9).

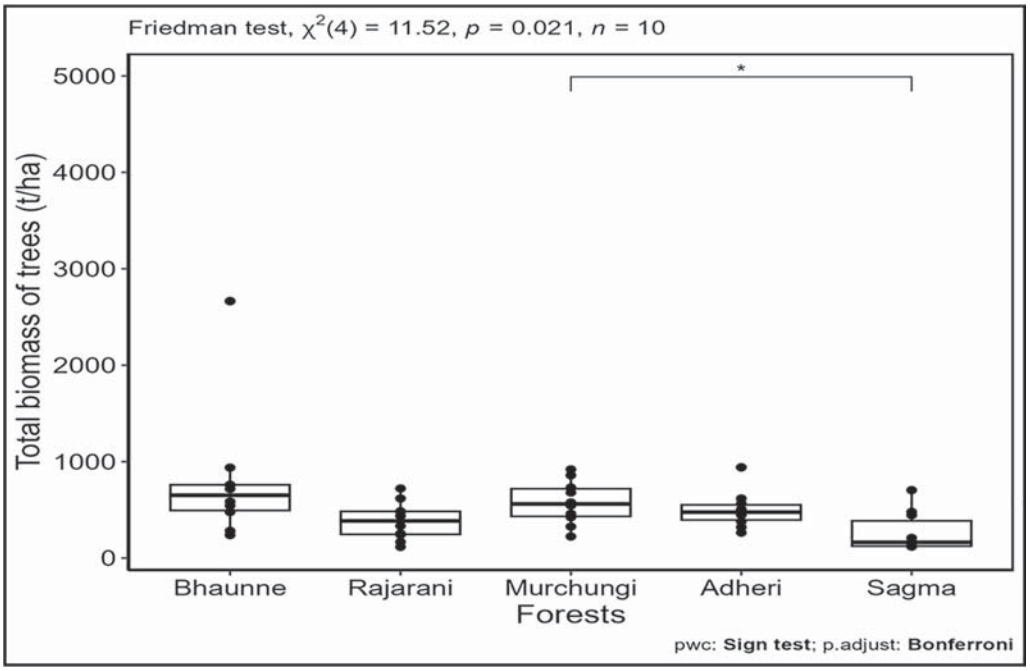

Figure 7: Relationship of total tree biomass (t/ha) among five forests located at different elevations of Morang District. Line covered forests inside figure with asterisk sign (*) indicated statistical significance pair after Friedman test (p < 0.05).

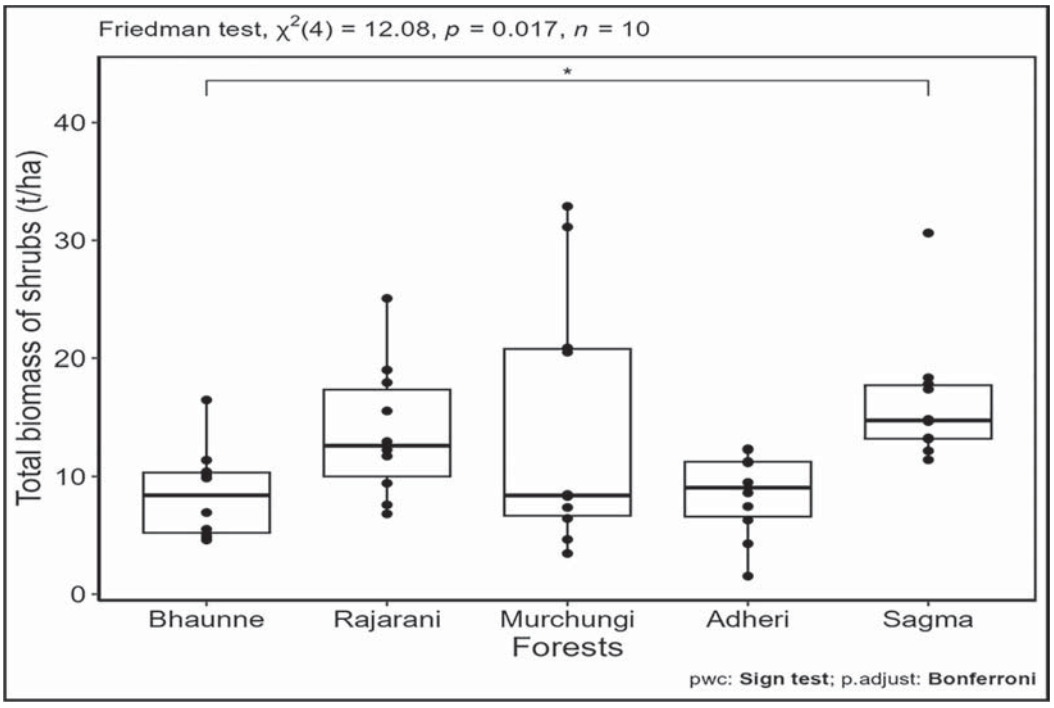

Figure 8: Relationship of total shrub biomass (t/ha) among five forests located at different elevations of Morang District. Line covered forests inside figure with asterisk sign (*) indicated statistical significance pair after Friedman test (p < 0.05).

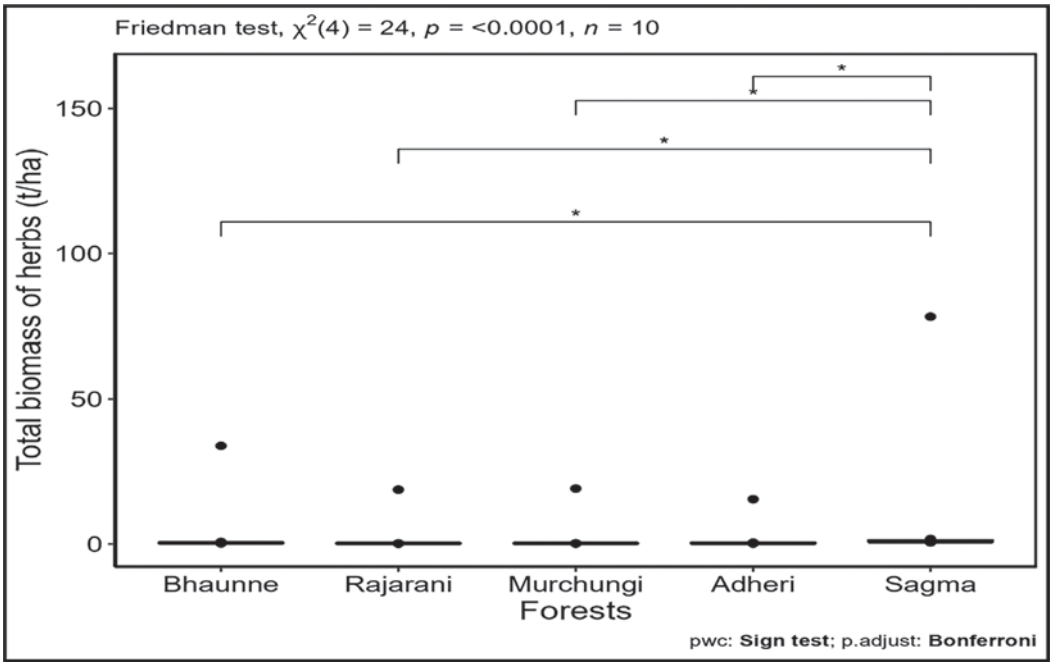

Figure 9: Relationship of herb biomass (t/ha) among five forests located at different elevations of Morang District. Line covered forest inside figure with asterisk sign (*) indicated statistical significance pair after Friedman test (p < 0.05).

Fine-root biomass and carbon stocks

The study revealed a higher fine-root biomass in the upper soil depth (0–15 cm), indicative of an efficient utilization of soil nutrients. Notably, fine-roots with <2 mm diameter exhibited greater dynamism in

nutrient supply due to their high turnover rate as compared to those with 2–5 mm diameter (Gautam & Mandal, 2016). The maximum fine-root biomass observed in the Murchungi site (see Figure 5 above) could be attributed to a potentially lower turnover rate, possibly associated with specific species characteristics (Pandey *et al*., 2023; Raich *et al*., 2009). The fine-root biomass displayed an increasing trend up to the Murchungi site, followed by a decrease with increase in elevation beyond this point.

The present study highlighted an extensive carbon stock in fine-root biomass with <2 mm diameter, likely influenced by various external factors such as soil nutrients and altitude in addition to internal factors (Bhattarai *et al*., 2020; Vogt *et al*., 1986; Wendy & Gordon, 2000).

The total fine root biomass for both below 2mm as well as 2-5 mm diameter did not show statistical significant results in the pairwise comparison among studied forests of varying elevations (Figures 10 and 11) though chi-square value of Friedman Test for fine root biomass below 2 mm was statistically significant (Figure 10).

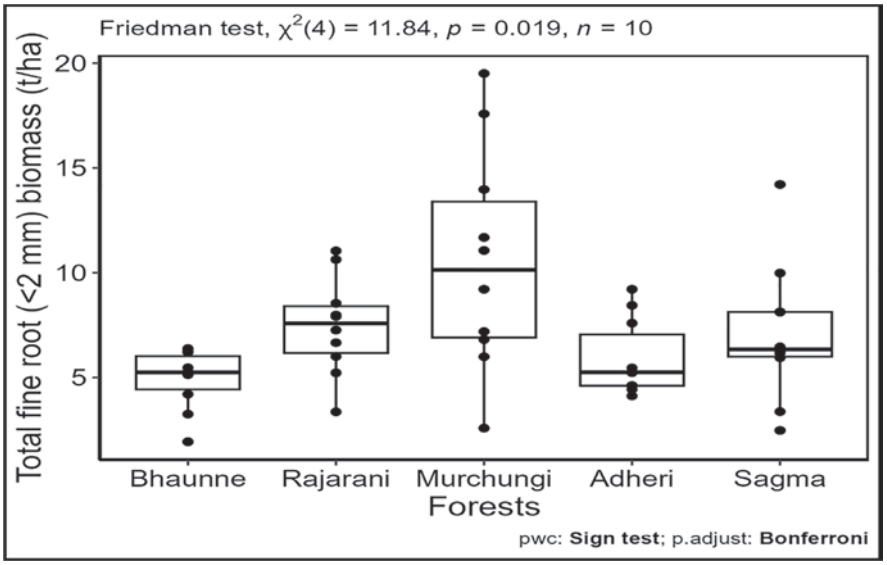

Figure 10: Relationship of fine root (<2 mm) biomass (t/ha) among five forests located at different elevations of Morang District. The pairwise comparison result plotted after Friedman test.

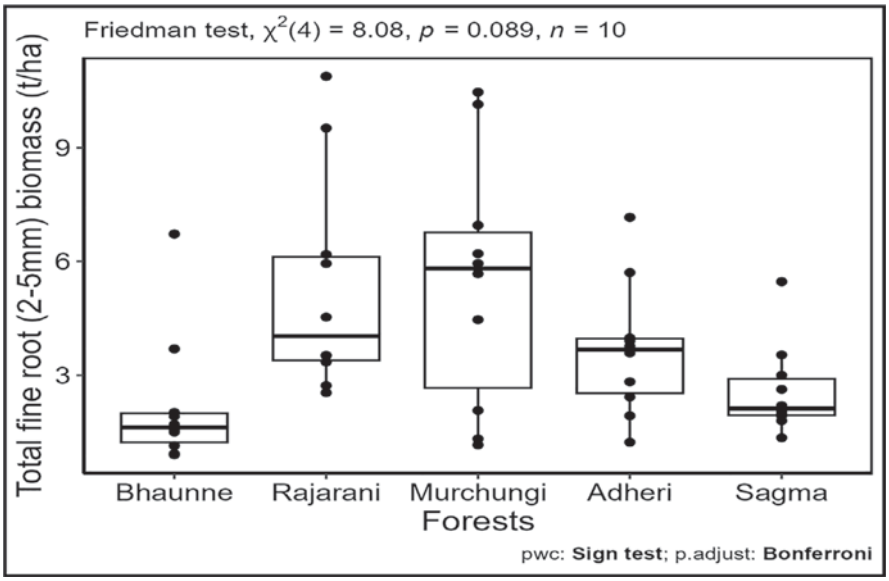

Figure 11: Relationship of fine root (2-5 mm) biomass (t/ha) among five forests located at different elevations of Morang District. The pairwise comparison result plotted after Friedman test.

Discussion

Plant biomass and carbon stock

The distribution of plant biomass and carbon stocks in the forest are known to affect by various factors, including the presence of different tree species, nutrient availability in the soil, and climate (Bhatta *et al*., 2018; Dani & Baniya, 2019; Gurung *et al*., 2022; Malla & Neupane, 2024). The current study suggests that total biomass and carbon stocks vary across sites in relation to different elevations. A higher biomass of 815.86 Mg ha^{-1} was observed in Bhaunne site, possibly due to the presence of various species with greater girth, such as *S. robusta* (Baral *et al*., 2009) while a lower carbon pool in Sagma forest may be due to the composition of different species, dominated by *Schima castanopsis*, which is similar to the findings of Khanal *et al*. (2008). Several other researchers (Shrestha & Singh, 2008; Mwakisunga & Majule, 2012; Gautam & Mandal, 2016; Bohara *et al*., 2021) have claimed that higher plant biomass is due to increase in tree density, which is in contrast with the findings of our study. We found that the aboveground biomass varied among the sites due to differences in plant species and community structure. In present study, the decline in carbon stocks in high-elevation forests might be due to steep slopes (Bohara *et al*., 2021; Pandey *et al*., 2020). However, an increase in the forest carbon stock in tropical lowlands may be due to the accumulation of more organic matter and other minerals in the less sloping areas as a result of heavy rainfall. This result is comparable to the findings of Leuschner et al. (2007), Moser et al. (2011), Sanquetta et al. (2013), Bhattarai & Mandal (2020) and Bohara et al. (2021).

Aboveground biomass and carbon exhibit wide variations in tropical forests, influenced by stem size distribution, soil fertility (Gautam & Mandal, 2013) and topography (KC *et al*., 2024; Castilho *et al*., 2006; Malhi *et al*., 2006). Baral *et al*. (2009) estimated 97.86 Mg C ha^{-1} in Hill *Shorea* forest, with a maximum stand height of 30 m and the mean height of 12.75 m, and the maximum DBH of 89 cm and the mean DBH of 19.56 cm.

A decline in aboveground biomass with the increase in elevation as reported by a number of researchers (Rana *et al*., 2023; Leuschner *et al*., 2007; Moser *et al*., 2011) are in line with the findings of this study while some others (Pokhrel & Sherpa, 2020; Thakur *et al*., 2024; Kumar *et al*., 2019; Thokchom & Yadava, 2017) have reported an increase in aboveground biomass with the increase in elevation. The range of aboveground biomass (230.74–641.13 Mg ha^{-1}) of the trees, shrubs, and herbs in the present study supports well with other studies in the tropical forests of Nepal. Ramachandran *et al*. (2007) reported a range of aboveground biomass (36.85 to 196.98 Mg ha^{-1}) in Kolli Hills of eastern Ghats, 7.92–307 Mg ha^{-1} in Chitteri Hills of eastern Ghats, 64.81–624.96 Mg ha^{-1} in Sathanur Reserve Forest, and 118–260 Mg ha^{-1} in Javadi Hills (Pragasan, 2014) of India.

The findings of the present study contradict with those of Behera *et al*. (2017), and Borah *et al*. (2013), Padmakumar *et al*. (2018) regarding the relationship between species diversity and biomass. The present study suggests that higher biomass is not always associated with higher diversity, which may be attributed to the tree density and girth size of individual species. A positive relationship between tree density and carbon stock was found by Pragasan (2014) which is similar to the present study. Thus, tropical forests of east Nepal act as C-accumulating systems, serving as significant global carbon sinks (Gautam & Mandal, 2016), similar to other wet tropical forests (Pan *et al*., 2011).

Conclusion

In conclusion, this study highlights the considerable variation in biomass and carbon stocks across the forests situated at different elevations in the Morang district of Nepal. The intricate relationship between fine-root biomass, carbon stocks and elevation, together with variations in fine-root diameter classes, unveiled a distinct ecological pattern. Notably, thinner-diameter fine-roots exhibited higher biomass compared to their thicker fine-root. The observed high fine-root biomass and carbon stocks in the upper layers of soil (0–15 cm) emphasized the

importance of this region for nutrient cycling and storage. The fine-root biomass of <2 mm and 2–5mm diameters across the forests were insignificant. This highlights a potential uniformity in fine-root dynamics despite variations in forest types and elevations, contributing valuable insights to our understanding of below-ground ecological processes.

The implications of these findings are expected to be useful in preparing practical guidelines for forest ecosystem management. Recognizing the intricate relationships between plant biomass and carbon stocks, fine-root biomass and carbon stocks with elevation can enhance strategies aimed at optimizing carbon storage and promoting sustainable forestry practices. This study contributes to the broader understanding of forest ecosystems and provides a foundation for decision-making in the realm of carbon management.

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Authors contribution:

Conceptual framework, data collection, and manuscript written by P. K. Gachhadar, Conceptual frame and manuscript written, statistical analysis, editing, reviewed, and correspondence by C. B. Baniya and Conceptual frame and manuscript written, editing and review T. N. Mandal.

Data availability:

The data used in this study are accessible upon request to the corresponding author.

Declaration

We have no conflict of interest in the publication of this research manuscript.

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Annex-I

Plotwise total biomass among five studied forests of Morang, East Nepal.

Forests	Plot	Tree_ biomass(t/ ha)	Shrub_ biomass (t/ha)	Herb_ biomass (t/ha)	Fine_root_less_ than_2mm (t/ha)	Fine_root_two_ five mm(t/ha)
Bhaunne	1	716.97	6.936	0.215	4.7	0.7
Bhaunne	2	937.48	10.4	0.423	3.9	1.26
Bhaunne	3	2664.76	9.872	33.86	2.42	0.75
Bhaunne	4	238.04	10.14	0.1975	4.99	6.42
Bhaunne	5	543.52	11.388	0.1902	3.88	2.97
Bhaunne	6	282.67	4.852	0.443	3.94	0.81
Bhaunne	7	477.18	4.608	0.3294	3.29	0.99
Bhaunne	8	757.3	16.5	0.35	1.66	0.93
Bhaunne	9	760.19	5.12	0.7589	2.89	1.11
Bhaunne	10	586.38	5.516	0.5266	2.9	1.03
Rajarani	1	721.18	7.592	0.2304	4.49	3.71
Rajarani	2	242.78	9.424	0.2011	5.11	3.79
Rajarani	3	167.77	11.736	18.73	5.15	8.95
Rajarani	4	334.07	12.964	0.1923	3.94	1.62
Rajarani	5	479.75	17.98	0.2011	3.06	0.17
Rajarani	6	115.38	12.26	0.11	4.56	1.16
Rajarani	7	485.23	25.072	0.1532	6.59	3.25
Rajarani	8	436.69	19.048	0.1955	3.36	4.12
Rajarani	9	617.87	15.568	0.1675	2.56	1.14
Rajarani	10	254.97	6.828	0.1987	4.98	1.85
Murchungi	1	576.54	20.868	0.2246	2.58	0
Murchungi	2	858.21	31.132	0.1456	11.62	3.81
Murchungi	3	731.31	6.432	19.12	9.91	4.16
Murchungi	4	545.19	7.368	0.256	5.77	3.7
Murchungi	5	459.07	20.508	0.209	0.55	0.05
Murchungi	6	919.01	4.652	0.1377	13.2	6.85
Murchungi	7	680.33	32.888	0.178	2.56	0.83

Forests	Plot	Tree_ biomass(t/ ha)	Shrub_ biomass (t/ha)	Herb_ biomass (t/ha)	Fine_root_less_ than_2mm (t/ha)	Fine_root_two_ five mm(t/ha)
Murchungi	8	223.56	3.46	0.1543	5.87	2.69
Murchungi	9	423.84	8.472	0.2021	7.56	4.78
Murchungi	10	326.16	8.304	0.2257	5.87	3.89
Adheri	1	566.56	12.272	0.4955	5.49	1.99
Adheri	2	320.14	6.304	0.1956	3.24	2.73
Adheri	3	263.7	11.276	15.44	3.27	0.48
Adheri	4	447.01	4.288	0.2013	2.69	1.32
Adheri	5	377.93	11.164	0.1249	5.9	2.83
Adheri	6	464.78	7.452	0.4605	2.48	1.07
Adheri	7	940.95	1.54	0.1867	2.7	3.11
Adheri	8	617.81	12.352	0.201	3.36	4.37
Adheri	9	487.27	9.492	0.4377	2.45	3.67
Adheri	10	507.67	8.608	0.2211	2.61	1.37
Sagma	1	444.89	14.852	0.5	2.35	1.5
Sagma	2	122.54	11.42	0.511	5.35	1.5
Sagma	3	208.71	13.272	78.2	4.49	0.71
Sagma	4	479.04	30.624	0.7512	4.18	2.42
Sagma	5	169.71	12.176	1.5013	11.02	4.6
Sagma	6	704.57	17.412	0.9001	1.53	0.34
Sagma	7	120.58	18.388	0.7511	3.34	1.65
Sagma	8	127.07	13.184	0.822	4.07	1.26
Sagma	9	119.37	14.668	0.8005	3.32	0.23
Sagma	10	155.73	17.868	1.7501	5.76	1.23

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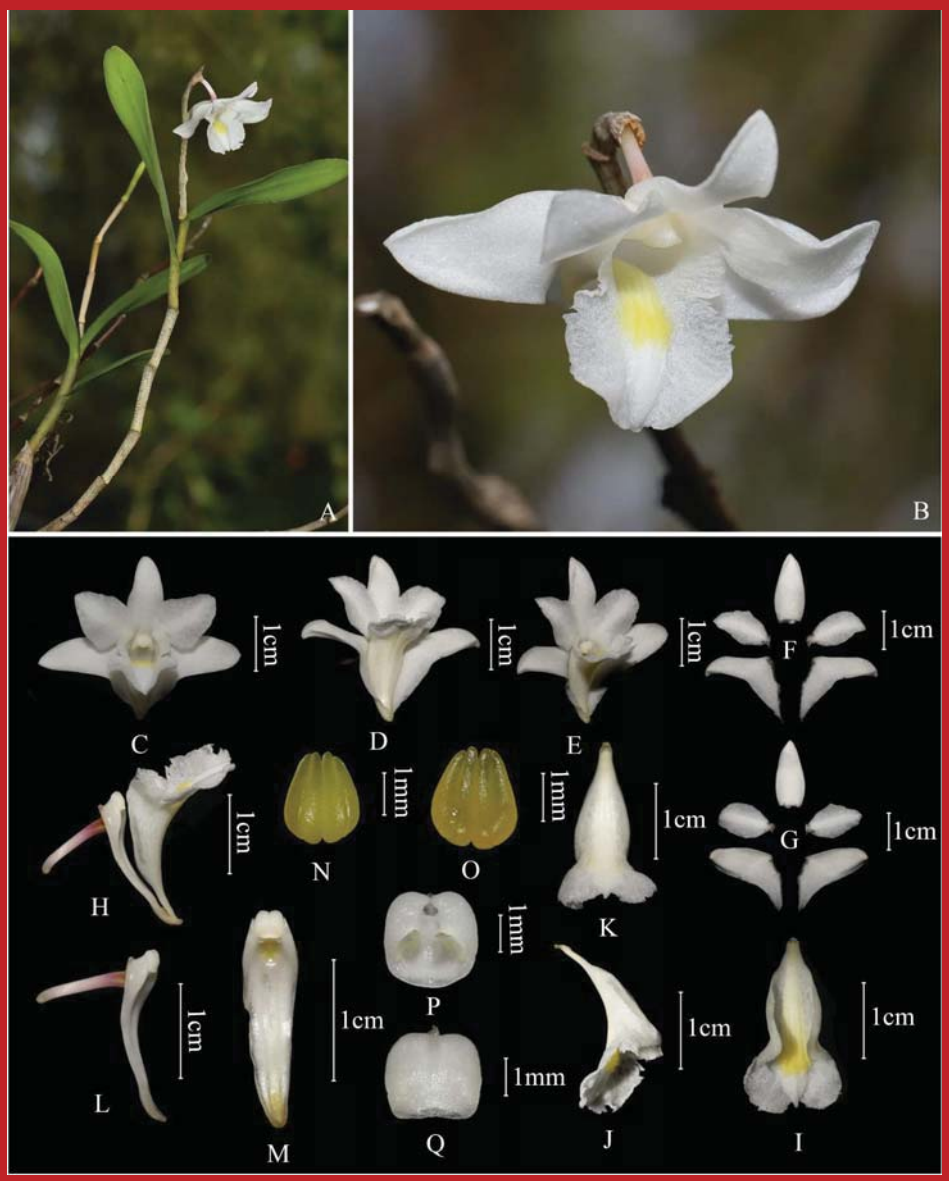

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Plants used in medicinal practices by the tribal people of Morang District in Koshi Province of Nepal

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Abstract

Access to formal healthcare facilities is limited in rural areas of Nepal, necessitating a reliance on traditional healers and medicinal plants for healthcare needs. This study aims to systematically document and preserve the indigenous knowledge of ethnomedicinal practices in the forests of eastern Nepal. Through meticulous data collection, preservation, identification, and documentation, this comprehensive study examines the medicinal plant species employed by 50 esteemed local elders. The findings reveal a remarkable diversity of 235 medicinal plant species, spanning 71 families and 195 genera. Gastrointestinal ailments emerged as the primary health concerns addressed by these plants. Furthermore, the Relative Frequency of Citation (RFC) and Informant Consensus Factor (ICF) were calculated to assess the significance of the identified plants. *Phyllanthus emblica* garnered the highest, 0.7 RFC value underscoring its prominent role in traditional medicinal practices among species. Similarly, the Fabaceae exhibited the highest, 300 Family importance value (FIV) value among families.

Key words: Ethnobotany, Traditional knowledge, Forest, Medicinal plant, Habit groups

INTRODUCTION

Plants encompass the quintessential foundation of life and its myriad of components. Almost 80% of world human population derive healthcare materials from plants (Hao & Xiao 2020; Saslis-lagoudakis *et al.* 2014). Rural communities possess greater accessibility to medicinal plants compared to their urban counterparts. Local healers have acquired their knowledge, attitudes, and behaviors necessary to preserve a healthy ecosystem. They depend on a range of plant resources for their financial security, income, and, most significantly, for their health care (Hamilton 2004; Lungphi *et al.* 2022). Their traditional knowledge of indigenous communities is important in the preparation of herbal remedies and in the isolation of bioactive constituents, which may lead to the discovery of novel drugs (Farnsworth 1990; Kathambi *et al.* 2020). Around 25 % of modern drugs are derived from plants (Newman & Cragg 2012). It is now crucial to properly document indigenous peoples' existing knowledge on plants and their traditional uses since it is accessible to everyone and environment-friendly (Aziz *et al.* 2018). However, socioeconomic shifts, changes in land use, excessive exploitation of natural resources, and climate change result in the loss of biodiversity and related traditional knowledge worldwide (Santamar & Mendez 2012; Slingenberg *et al.* 2009; Smith 2018). Young people prefer modern medicines causing indigenous knowledge vulnerable (Hussain *et al.* 2018).

Nepal is a country where highly diverse ethnicity contributed to its rich cultural heritage and traditional knowledge on the uses of plant resources. It has been estimated that around 2,000 plant species have medicinal uses (Manandhar 2003). About 85% of the total population in Nepal relies on traditional herbal medicines for primary healthcare (Manandhar 1993, 2003; Kunwar *et al.*, 2013; Ghimire 2008)). As much as 85 % people of Nepal live in rural areas

(Anonymous 2019]) for whom it is challenging to get modern health care support provided by the government. According to a report there are only two doctors available for each 10,000 inhabitants. This number is least as compared to countries of the world, such as Europe, United States, Australia where 33 doctors will be available for every 10,000 people on average (with a low of 19 in Romania and a maximum of 54 in Greece) (Anonymous 2010). Under such a situation, people try to remain safe with their plant-based knowledge. This traditional knowledge, which is primarily transmitted verbally for generations within families or in small groups of healers who practice folk, shamanic, and Ayurvedic medicines (Aryal *et al.* 2016).

Although, herbal medicines are widely use but there is rapid loss of traditional knowledge on medicinal plants due to rapid urbanization, immigration, and climate change (Luitel *et al.* 2014; Rokaya *et al.* 2010).

There have been around 35,000 to 70,000 plant species used as medicinal purposes in the world (Kiarash Afshar *et al.* 2012) among them about 6,500 species were reported from Asia (Karki & Williams 1997). Transmission of indigenous knowledge to new and younger generations will be hindered by fast growing urbanization and higher number of youth immigration in search of better economic opportunities, which will lead to a loss of traditional knowledge. The availability of medicinal plants is threatened by deforestation, habitat loss, and encroachment on forest land for agriculture and urbanization. Thus, it is critical to document traditional knowledge of plant resources for their sustainable use and to develop conservation strategies and policies. It is crucial to document the medicinal plants found throughout their region as well as their associated traditional knowledge. Therefore, the current study was conducted in Letang, Raja-Rani and surrounding forests in Morang district of East Nepal to record the medicinal plant species and their traditional use patterns among people of local communities. The recorded data will be helpful to develop sustainable use and conservation strategies and policies for plant resources in Nepal. Such information may also aid in the preservation of genetic and cultural diversity, as well as conservation and sustainable use of local plant resources (Chaudhary *et al.* 2015; Hanazaki *et al.* 2013; Rodrigues *et al.* 2020).

STUDY AREA

This study was conducted in the five forests located at different elevations in the Morang district of the Koshi Province in eastern Nepal (Figure 1). The elevation of study area ranges from 100 to 1300 m amsl. Among the five forests, four: Raja-Rani, Murchungi, Adheri and Sagma lies in ward number 1 of Letang municipality. The remaining one, Baunne is belonged to ward number 10 of Belbari municipality. Bhaunne, Raja-Rani, Murchungi, Adheri and Sagma forests belonged to Belbari-Chisang community forest, Raja-Rani community forest, Akashe community forest, Shat kanya community forest and Kuwapani community forest respectively (Table1).

The dominating floristic elements in the study area were Sal (*Shorea robusta*), Chilaune *(Schima wallichii),* Bhalayo (*Semecarpus anacardium*), Dhusuro (*Colebrookea oppositifolia*), Rajbrikshya (*Cassia fistula*), Tatari (*Dillenia pentagyna*), Sindure *(Mallotus philippensis)*, Odane (*Sterculia villosa*), Chhatiwan (*Alstonia scholaris*), Katus (*Castanopsis indica*), Chanp (*Magnolia champaca*), Bharlo (*Phanera vahlii*), Khanyu (*Ficus hispida*), Dabdabe (*Garuga pinnata*), etc. Invasive alien plant species such as Banmara (*Chromolaena odorata*), Banmara (*Ageratum conyzoides*) etc. are also dominating in open and partially open areas.

Latitudes and longitudes of studied area ranged from 26°39'45.69" N to 26°48'28.68" N and 87°28'2.08" E to 87°28'45.06" E respectively. The total population of Ward no. 1 of Letang Municipality is 3717 (https://letangmun.gov.np/en/ward-profile?page=1). The vil-

Figure 1: Location map of study area in Nepal

lages nearby the study area are Kirtiman, belbari, Fadani, Lokaraha, Raja-Rani, Budhbare–Adhere, Koikunda, Kuwapani, Kartike and Hardiyaa. Respondents were mostly belonged to Limbu, Magar, Rai, and Tamang communities. They represent major ethnic groups for the study area. Their sources of income are mainly agriculture farming, hired-labor, fire-wood collection, etc.

Table 1: General information on study sites

Sites	Elevation (m amsl)	Municipality	Community forest	Total Area (Hectare)	House holds	Popula-tion	Forest types
Bhaunne	100 – 250	Belbari, ward no.-10	Belbari-Chisang	1646.64	35997	193361	Natural
Raja-Rani	380 – 600	Letang, ward no.-1	Raja-Rani	299.5 (Block 4: 148.28)	188	877	Natural
Murchungi	700 – 880	Letang, ward no.-1	Akashe	146.05	90	462	Natural
Adheri	900 – 1050	Letang, ward no.-1	Shaat kanya	119.8	63	366	Natural
Sankma	1100 – 1300	Letang, ward no.-1	Kuwapani	206.15	44	262	Natural

Climate

Three distinct seasons are recognizable: (i) a hot and humid summer; (ii) a rainy-monsoon; and (iii) a cold-dry winter. Data from Dharan Meteorological station represents the climate of Bhaunne, Raja-Rani, Murchungi and Adheri forests. Likewise, meteorological data of Dhankuta station represents the climate of Sagma forests. Meteorological data analysis of both stations (Figure 2) showed that the study areas fall within the moist climatic zone, raining throughout the year and their average temperature remain low due to the high precipitation in the area. However, November – December represents the dry period.

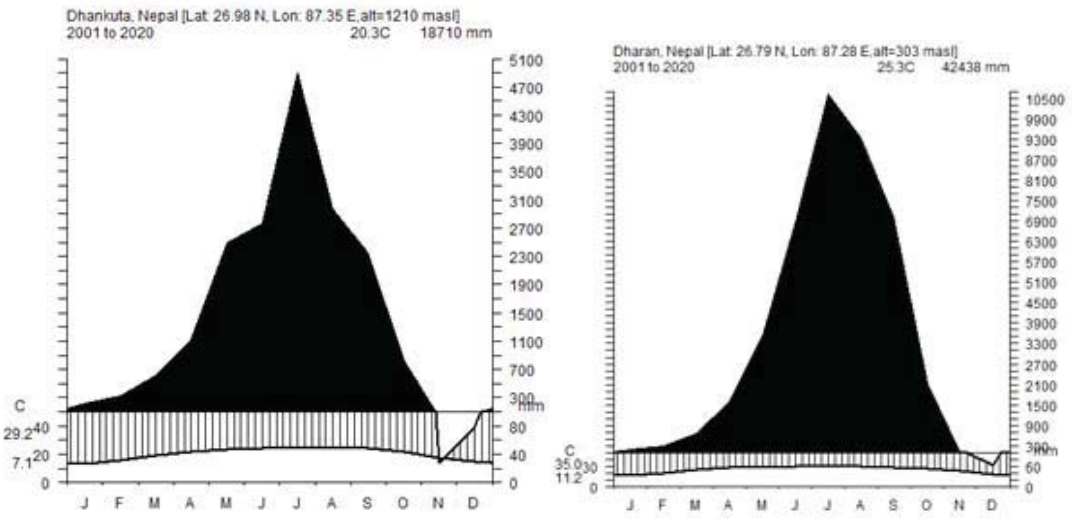

Figure 2. Ombothermic graph showing relation between temperature and precipitation of study area [*Source*: Department of Meteorology, Dharan, Nepal]

Sagma forests have average annual minimum temperature ranged from 7^0 C to 20.8^0 C, whereas average annual maximum temperature was ranged between 19.57^0 C to 29.21^0 C. The total annual rainfall was 27.9 - 4908.6 mm. Similarly, average annual minimum and maximum temperature of Bhaunne and Raja-Rani, Murchungi and Adheri forests ranged from 11.18^o C to 24.62^o C and 21.4^o C to 34.98^o C respectively. The recorded highest annual rainfall was 10630.12 mm in July (2000 – 2022).

MATERIALS AND METHODS

Survey of Medicinal plants

The survey of medicinal plants in selected five forests of Morang district in East Nepal was done during 2020 to 2023. The survey was fully concentrated on traditional practices of plants used as medicinal by locals living in nearby villages. Mainly elderly people and traditional healers (*Dhami, Jhakri*) were chosen as informants. They were consulted with the help of open-ended semi-structured questionnaires. For ethnomedicinal survey questionnaire was prepared following Martin (1995) that included personal data of the informer (age, profession, education), plants and plant-parts used, methods of preparation and administration of medicines. However, mandatory FPIC was taken from the respondents before the start of discussion. Plant specimens pointed out and mentioned by respondents were collected and photographed. Collected voucher specimens were processed and mounted in herbarium sheets following Jain & Rao (1977) and

Das (2021). Photographs of respondents were taken with their permission. The collected plant specimens were identified with the help of available standard literature (Hooker 1872 – 1897; Hara *et al.* 1978, 1982, Hara & Williams 1979; Grierson & Long 1983, 1984, 1987, 1991, 1999, 2000, 2001; Press *et al.* 2000; Grierson *et al.* 2002; Polunin & Stainton 1984; Polunin *et al.* 1987; Stainton & Polunin 1988; Obha *et al.* 2008; Rajbhandari & Rai 2017). All plant species and photographs were verified after comparing with specimens stored in herbarium at Post Graduate Campus, Biratnagar, Tribhuvan University, Nepal and expert consultation. Accepted and updated names were checked through the website Powo.science.kew.org published by the Royal Botanic Gardens, Kew. All the voucher specimens were deposited at TUCH. The data were then processed and statistically analyzed using MS Excel.

Nomenclature of all the plant species were verified with www.plantsoftheworldonline.org and their family delimitation were based on the Angiosperm Phylogeny Group-IV (APG-IV) system of classification by Chase *et al.* (2016).

Statistical Analysis of Data

The study utilized quantitative methods for data analysis. Quantitative analysis involved the measurement of the Family Importance Value (FIV), Relative Frequency of Citation (RFC), and Informant Consensus Factor (ICF).

1. Family Importance Value (FIV)

The relative importance of each plant families was calculated through the determination of Family Importance Value (FIV) following Sulaiman *et al.* (2020) with the formula:

$$FIV = FC / N \times 100,$$

Where, FC is the number of informants who mentioned the family and N is the total number of informants interviewed.

2. Relative Frequency of Citation (RFC)

The RFC measures the usefulness of a particular plant species. RFC was computed by using the formula as given by Budiarti *et al.* (2020).

$$RFC = FC/N \quad (0<RFC<1)$$

Where FC = frequency of citation, N = total number of informants.

The relative frequency of citation is obtained by dividing the number of informants mentioning a useful species frequency of citation by the total number of informants interviewed in the research.

3. Informant Consensus Factor (ICF)

The ICF was used to determine the homogeneity of information about medicinal plants. ICF was calculated using the formula given by Heinrich *et al.* (1998):

$$ICF = (Nur - Nt) / (Nur - 1)$$

Here, 'Nur' refers to the total number of use reports for each ailment category, and 'Nt' is the number of taxa used in that category.

RESULTS AND DISCUSSION

A total of 50 key informants were interviewed in the study area, all of whom had firsthand knowledge on medicinal plants used by them. It denoted us that respondents selected had wider knowledge on medicinal uses of plants as for the communities knowledge of plant-use can be expanded by using such a random and wide selection of participants (Gomez-beloz 2002). The study revealed that the informants obtained knowledge about plant uses mostly

from their parents Pardo-De-Santayana *et al.* (2015) and Polat *et al.* (2015) also mentioned the same.

Traditional medical treatments are frequently a gender-based profession carried out by both men and women (Oliver 2013). The data showed that in the study area, 58 % of females and 42 % of males had knowledge of medicinal plants, indicating that women hold more information about medicinal plants. The higher percentage of female informants may be due to their more responsibility for collecting and preparing medicine and other uses for their families and households.

Regarding education level, majority of the participants were less educated (having informal education only). The data analysis revealed that 56% of the participants had informal education, 26% held secondary level education, 10% had intermediate (12 grade) level education, 4% had primary level education, and the remaining 4% had Bachelor level education (Table 2).

In terms of profession, the largest percentage of respondents (64%) was farmers who mainly depend on agriculture. Similar results were accessed from many studies (Ladio & Lozada 2004; Teklehaymanot & Giday 2007; Giday *et al.* 2009). According to respondents, younger or educated people are not that much interested in traditional medicinal practice as they mostly remain out of their villages. Hussain *et al.* (2018) also recorded that knowledge on use of medicinal plants is vanishing gradually among younger generation people of the society. This might be because of their changing life styles and easy access to allopathic medicines (Gachhadar 2006; Saslis-Lagoudakis *et al.* 2012). The informants between the ages of 30 – 60 years had more knowledge of medicinal plants, while only 6 % of respondents below 30 years old had such knowledge. Additionally, it was observed that young people were not much interested in traditional knowledge, as 42 % of respondents aged 61 years and above had information on medicinal plants. The demographic characteristics obtained in the study are summarized in the Table 2.

Table 2. Different demographic details of Informants

Demographic variables	Details of different categories	Informants (%)
Profession	Agriculture	64
	Healer	10
	Social worker	10
	Business	6
	Labourer	6
	Service	4
Gender	Male	42
	Female	58
Education Background	Informal education	56
	Secondary	26
	I.A.	10
	Primary	4
	Bachelor	4
Age	<30	6
	31-60	52
	>61	42

Diversity of Ethnomedicinal Plants

Nepal is the home to an abundance of medicinal plants because of its varied climatic and ecological conditions (Rokaya *et al.* 2010). Present ethnobotanical survey recorded as much as 235 species of medicinal plants representing 71 families and 195 genera (Table 3). These medicinal plants were used for 63 various ailments like dysentery, diarrhea, throat problems, cancer, jaundice, menstruation, fever, eye problems, gastric, cough and cold, skin diseases, liver problems, bone fractures, bacterial infections etc. which are grouped into 17 usage categories: Kidney problems, Cancer problems, Hair care, Infectious diseases, Poisonous bites, Cardiovascular diseases, Bone diseases, Urinogenital and reproductive disorders, Liver problem, Skin infections, Wound healing, Optical complications, High glucose level, Aches, Respiratory system illness, Gastrointestinal diseases and General health (Table 5). The most prominent families were Asteraceae (29 spp.) followed by Fabaceae (25 spp.) and so on (Table 4).

Table 3: Numerical diversity of medicinal plants and their species and family levels in the study area

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
1	*Abutilon indicum* (L.) Sweet [Malvaceae]; *Pramila-273*	*Atibalu*	H	Root	Juice	Toothache (9)
2	*Achyranthes aspera* L. [Amaranthaceae]; *Pramila-058*	*Datiwan, Apamarga*	H	Root	Paste	Cough (4) and Cold (2)
3	*Achyranthes bidentata* Blume [Amaranthaceae]; *Pramila-175*	*RatoDatiwan, RatoApamarga*	H	Whole plant	Decoction	Sore throat (6)
4	*Actinodaphne lanceolata* Daizell & A. Gibson [Lauraceae]; *Pramila-206*	*Jhakriseuli ,Jhakri Kath*	T	Leaf	Juice	Urinary disorder (5)
5	*Adenostemma lavenia* (L.) Kuntze [Asteraceae]; *Pramila-169*	*Ratodatheghans*	H	Leaf	Juice	Fatigue (3)
6	*Aegle marmelos* (L.) Correa [Rutaceae]; *Pramila-274*	*Bael, Bel*	T	Fruit, Leaf	Juice	Gastric problem (16), Stomachache (6)
7	*Ageratina adenophora* (Spreng.) R.M.King & H. Rob. [Asteraceae]; *Pramila- 129*	*Kalo Banmara, Kalo Raunne*	S	Leaf	Juice	Cut and wounds (6)
8	*Ageratum conyzoides* L. [Asteraceae]; *Pramila-081*	*Ilamejhar, Gandhe*	H	Leaf	Juice, Decoction	Cut and wounds (5), Stomach disorder (2)
9	*Ageratum houstonianum* Mill. [Asteraceae]; *Pramila- 319*	*Nilogandhe*	H	Leaf	Juice	Heart Pain (2)
10	*Alangium salviifolium* (L.f.) Wangerin [Cornaceae]; *Pramila-238*	*Ashare, Anurukha*	T	Leaf	Juice	Diabetes (3), Wound (5)
11	*Albizia lebbeck* (L.) Benth. [Fabaceae]; *Pramila-357*	*Kalo Sirish*	T	Bark, Leaf, Root and Stem bark	Paste, Juice, Powder	Diabetes (2), Prostrate problem (1) and Skin diseases (3)
12	*Albizia julibrissin* Durazz. [Fabaceae]; *Pramila-351*	*Rato Siris*	T	Flower, Stem	Extraction, Oils	Wound (5)
13	*Albizia lucidor* (Steud.) I. Neielsen ex H. Hara [Fabaceae]; *Pramila-200*	*Potka siris, Padke siris*	T	Bark	Juice, Paste	Fish poison (7)
14	*Albizia procera* (Roxb.) Benth. [Fabaceae]; *Pramila- 105*	*SetoSirish, Thakar*	T	Bark	Juice	Dandruff (3)
15	*Alnus nepalensis* D.Don [Betulaceae]; *Pramila-054*	*Utish*	T	Bark	Powder	Cut (3) and burns (5)
16	*Alocasia fornicate* (Kunth) Schott [Araceae]; *Pramila- 208*	Araceae	H	Leaf, Root, Flower	Paste	Jaundice (3)
17	*Alstonia scholaris* (L.) R.Br. [Apocynaceae]; *Pramila-045*	*Chhatiwan*	T	Leaf, Bark, Stem	Paste, Powder	Diabetes (4), Wounds (6), Tuberculosis (2)
18	*Alysicarpus vaginalis* (L.) DC. [Fabaceae]; *Pramila- 275*	*Jhar*	H	Root	Decoction	Cough (2)
19	*Anamirta cocculus* (L.) Wight & Arn. [Menispermaceae]; *Pramila-331*		H	Leaf, Fruit	Paste, Juice	Dysentry (4)

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20	*Anisomeles indica* (L.) Kuntze [Lamiaceae]; *Pramila-324*		H	Leaf	juice	Skin diseases (2), Stomach pain (1)
21	*Aporosa octandra* (Buch.-Ham. ex D. Don) Vickery; [Phyllanthaceae]; *Pramila-006*	*Charakofal*	T	Leaf	Paste	Bone injury (2)
22	*Argyreia atropurpurea* (Wall.) Raizada [Convolvulaceae]; *Pramila-003*		H	Leaf	Extraction	Wounds (2)
23	*Arisaema erubescens* (Wall.) Schott [Araceae]; *Pramila-109*	*Sarpa Makai*	H	Rhizome	Juice	Stomach disorder (3)
24	*Artemisia indica* Willd. [Asteraceae]; *Pramila-019*	*Titepati, Chiraito*	S	Leaf	Juice	Blood pressure (10), Diabetes (6), Cough (3)and diarrhea (4)
25	*Barleria strigosa* Willd. [Acanthaceae]; *Pramila- 163*	*Kuro*	S	Whole plant	Juice	Urinary disorder (3)
26	*Barleria cristata* L. [Acanthaceae]; *Pramila-276*	*Bhede Kuro*	H	Root, Bark, Flower	Paste	Toothache (3), inflammation (2)
27	*Bauhinia malabarica* Roxb. [Fabaceae]; *Pramila-358*	*Amiltanki*	T	Leaf, Stem	Juice	Wound (4), Urinary problems (3)
28	*Begonia picta* Sm. [Begoniaceae]; *Pramila-124*	*Magarkachi*	H	Leaf	Juice	Loss of Appetite (2)
29	*Berberis napaulensis* (DC.) Spring. [Berberidaceae]; *Pramila- 277*	*Chutro*	S	Fruit, Bark	Juice	Urine disorder (3)
30	*Bergera koenigii* L. [Rutaceae]; *Pramila-010*	*Curry patta, Mithonim, Khole jamun*	S	Leaf	Paste	Stomachache (6)
31	*Bidens pilosa* L. [Asteraceae]; *Pramila- 133*		H	Leaf	Juice	Cuts and wounds (5)
32	*Biophytum sensitivum* (L.) DC. [Oxalidaceae]; *Pramila-108*		H	Leaf	Juice	Diabetes (2), Stomach disorder (3)
33	*Blainvillea acmella* (L.) Philipson [Asteraceae]; *Pramila- 113*		H	Leaf	Paste, Juice	Diarrhea (1), Stomach disorder (2)
34	*Blumea balsamifera* (L.) DC. [Asteraceae]; *Pramila-025*		H	Whole plant	Paste	Diuretic (3)
35	*Blumea eriantha* DC. [Asteraceae]; *Pramila-157*	*Ganthe*	H	Whole plant	Juice	Cuts and Wounds (5)
36	*Blumea lacera* (Burm.f.) DC. [Asteraceae]; *Pramila-325*		H	Leaf	Juice	Cuts and wounds (6)
37	*Boenninghausenia albiflora* (Hook.) Rechb. ex Meissn. [Rutaceae]; *Pramila- 119*	*Makhe Mauro, Parewaaandre*	S	Leaf	Juice	Cuts and wounds (5)
38	*Boerhavia diffusa* L. [Nyctaginaceae]; *Pramila-335*	*Punarnava*	H	Root	Paste	Cough (3) and Jaundice (2)
39	*Bombax ceiba* L. [Malvaceae]; *Pramila-048*	*Simal*	T	Stem, Root, Flower	Decoction	Urinary infection (4) diarrhea and dysentery (8), Flower nutritious for Cattles (3)
40	*Breynia retusa* (Dennst.) Alston. [Phyllanthaceae]; *Pramila- 215*		S	Leaf, fruits, Twigs	Juice	Body pain (2), Dysentery (4)
41	*Bridelia retusa* (L.) A. Juss. [Phyllanthaceae]; *Pramila-352*	*Gayo*	T	Whole plant	Juice, Powder	Urinary problem (1)
42	*Brucea javanica* (L.) Merr. [Simaroubaceae]; *Pramila-209*	*Bhakmilo, Amilo*	T	Fruit	Decoction	Blood purifier (4), Stomachache (3)
43	*Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Sweet [Solanaceae]; *Pramila- 311*	*Datura*	S	Leaf	Decoction	Headache (2), Skin diseases (4), Inflammation (4), Swelling (2)
44	*Butea buteiformis* (Voigt) Grierson [Fabaceae]; *Pramila-029*	*Bhujretro, Hattikane*	S	Seed	Paste	Worm (6)
45	*Cajanus scarabaeoides* (L.) Thouars [Fabaceae]; *Pramila- 213*		H	Leaf, Root	Paste	Constipation (3)
46	*Callicarpa arborea* Roxb. [Lamiaceae]; *Pramila-016*	*Ban geyalo/ Kharmak,*	T	Bark	Paste	Dysentery (3), Common cold (6)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
47	*Callicarpa macrophylla* Vahl. [Lamiaceae]; *Pramila-016*	*Daikamla, Daichamle, Guyelo*	T	Root	Juice	Fever (7)
48	*Careya arborea* Roxb. [Lecythidaceae]; *Pramila-359*	*Kumbhi*	T	Leaf, Latex	Juice, Latex	Urinary probem (5), Cuts and Wounds (7), Tonsils (3)
49	*Caryota urens* L. [Arecaceae]; *Pramila-379*	*Rang vang, Rangtang*	T	Bark, Tender, Flower	Paste	Hair loss (3)
50	*Cassia fistula* L. [Fabaceae]; *Pramila-075*	*Raajbriksha*	T	Leaf, Fruits, Bark	Juice, Raw	Cold and Cough (5), diarrhea (3)and dysentery (3)
51	*Catunaregam spinosa* (Thunb.) Tirveng. [Rubiaceae]; *Pramila-348*	*KandeMaidal*	S	Fruit	Decoction	Bronchitis (2) and Asthma (2)
52	*Celastrus paniculatus* Willd. [Celastraceae]; *Pramila- 249*		S	Bark, Seed	Paste	Stomach disorder (2)
53	*Centella asiatica* (L.) Urb. [Apiaceae]; *Pramila- 187*	*Ghortapre*	H	Whole plant	Juice	Gastric (6), Urinary stone (3)
54	*Chonemorpha fragrans* (Moon) Alston [Apocynaceae]; *Pramila-344*	*Gothali*	S	Leaf	Juice	Skin diseases (5)
55	*Chromolaena odorata* (L.) R.M.King & H.Rob. [Asteraceae]; *Pramila-033*	*SetoBanmara, SetoRaunne, Aulebanmara*	S	Leaf	Juice	Cuts and wounds (7)
56	*Chrysopogon aciculatus* (Retz.) Trin. [Poaceae]; *Pramila- 127*	*Kuro Ghans*	H	Root	Paste or Juice	Boils (4)and Wounds (3)
57	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & C.H. Eberm. [Lauraceae]; *Pramila- 272*	*Sinkauli, Tejpaat*	T	Leaf	Paste	Cold and Cough (17)
58	*Cipadessa baccifera* (Roxb. ex Roth) Miq. [Meliaceae]; *Pramila- 125*	*Paineti*	S	Bark, Root	Juice	Indigestion (2)
59	*Clematis buchananiana* DC. [Ranunculaceae]; *Pramila-063*	*Abijalo*	H	Whole plant	Juice	Cuts and wounds (2)
60	*Clerodendrum colebrookeanum* Walp. [Lamiaceae]; *Pramila- 182*		S	Shoot	vegetable	High blood pressure (3)
61	*Clerodendrum infortunatum* L. [Lamiaceae]; *Pramila- 192, 195*	*Dhatu, Bhanti, Chitu, Rajbeli, kalo*	S	Root, Leaf	Paste	Ringworm (8)
62	*Colebrookea oppositifolia* Sm. [Lamiaceae]; *Pramila-035*	*Dhusure, Dhursul, Dhursule, Dhusuro*	S	Root, Leaf	Juice	Jaundice (4), Cold (3)
63	*Combretum roxburghii* Spreng. [Combretaceae]; *Pramila- 312*	*Thakauli/ Kalo lahara*	S	Young leaf	Hot leaf juice	Wounds (leg wounds made by mud in rainy season) (5)
64	*Commelina benghalensis* L. [Commelinaceae]; *Pramila-329*	*Kanejhar*	H	Whole plant	Juice	Sore throat (3)
65	*Commelina suffruticosa* Blume [Commelinaceae]; *Pramila-264*	*Kanejhar*	H	Root	Juice	Problem in blood circulation (4)
66	*Cornus oblonga* Wall. [Cornaceae]; *Pramila-360*	*Lati kath*	T	Bark	Paste	Injuries (5)
67	*Cosmos bipinnatus* Cav. [Asteraceae]; *Pramila-330*		H	Whole plant	Decoction	Sore throat (5)
68	*Crassocephalum crepidioides* (Benth.) S. Moore. [Asteraceae]; *Pramila- 130*	*Anikaale]har*	H	Root, Leaf	Paste, Juice	Cuts and Wounds (2), Boils (1)
69	*Croton persimilis* Mull.Arg. [Euphorbiaceae]; *Pramila- 278*	*Aunle, Aulea*	T	Whole plant	Juice	Jaundice (3), Piles (2)
70	*Curculigo* orchioides Gaertn. [Hypoxidaceae]; *Pramila- 266*	*Syal Dhoti*	H	Root, Whole part	Paste, Juice	Jaundice (2), Asthma (1) and piles (1)
71	*Curcuma angustifolia* Roxb. [Zingiberaceae]; *Pramila- 378*	*Haledo, Kalo Haledo, Ban Besar*	H	Rhizome	Paste and Juice	Urinary disorder (5), bone fracture (2)

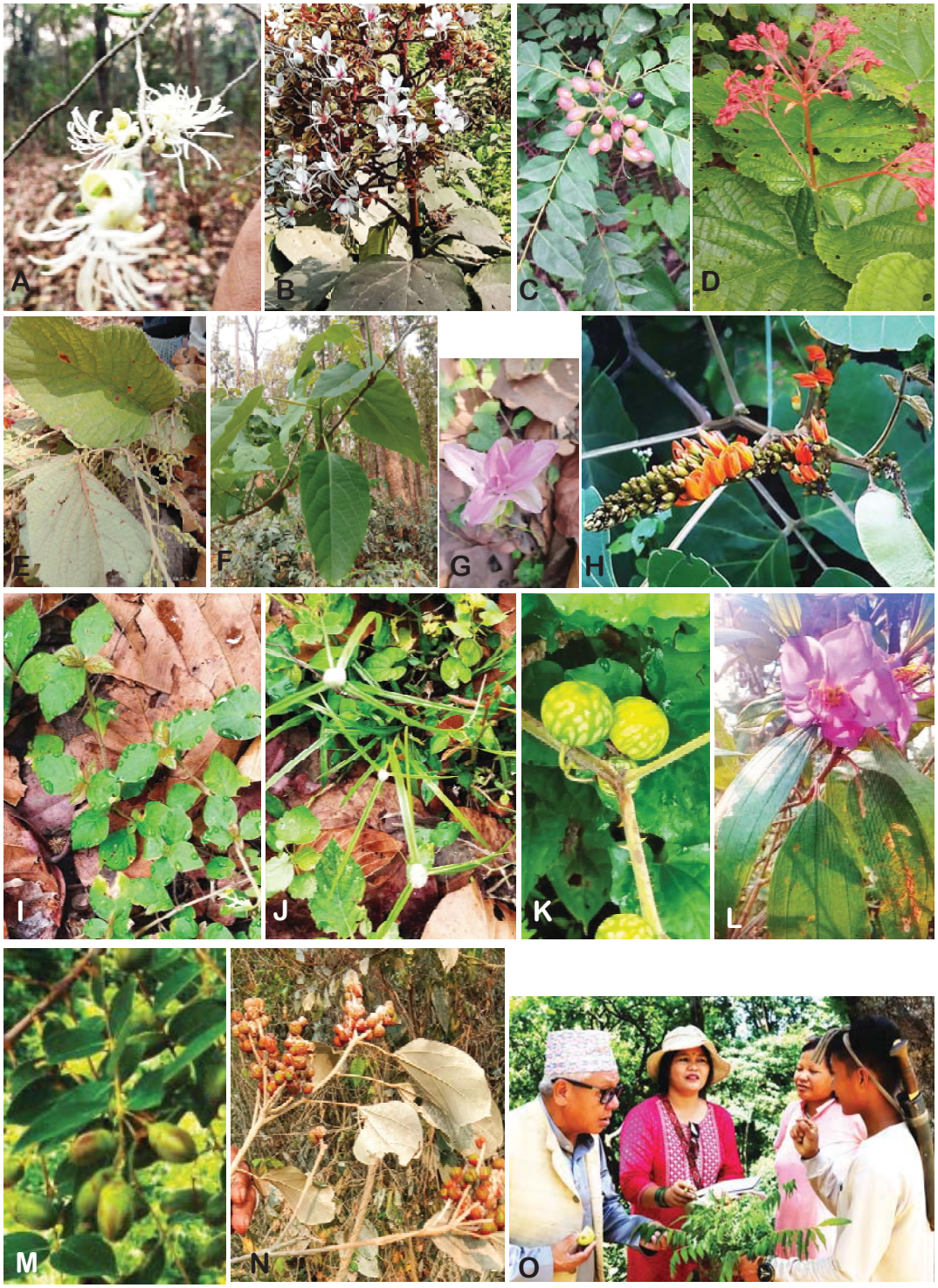

PLATE – I. Photos of some medicinal plants recorded from the study area: **A.** *Alangium salvifolium;* **B.** *Clerodendrum infortunatum;* **C.** *Bergera koenigii;* **D.** *Clerodendrum japonicum;* **E.** *Maesa macrophylla;* **F.** *Gmelina arborea;* **G.** *Curcuma angustifolia;* **H.** *Butea butiformis;* **I.** *Cyathula prostrata;* **J.** *Kyllinga brevifolia;* **K.** *Solanum viarum;* **L.** *Osbeckia stellata;* **M.** *Lagerstroemia parviflora;* **N.** *Mallotus philippensis;* **O.** Authors working in the field

A

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72	*Cyanthillium cinereum* (L.) H.Rob. [Asteraceae]; *Pramila- 279*		H	Leaf	Decoction	Fever (3)
73	*Cyathula prostrate* (L.) Blume [Amaranthaceae]; *Pramila- 279*		S	Leaf, Root	Juice	Toothache (3)
74	*Cynodon dactylon* (L.) Pers. [Poaceae]; *Pramila-057*	*Doobo,,SetoDubo*	H	Whole plant	Paste, Powder, Juice	Ulcer (2), Cancer (1), Gastric (6)
75	*Cyperus brevifolius* (Rottb.) Hassk. [Cyperaceae]; *Pramila-139*	*Mothe*	H	Leaf	Juice	Diarrhea (3)
76	*Cyperus rotundus* L. [Cyperaceae]; *Pramila-044*	*Mothe*	H	Root	Juice	Intestinal worm (7)
77	*Dalbergia latifolia* Roxb. [Fabaceae]; *Pramila-085*	*Satisal*	T	Bark, Leaf, Stem	Juice, Powder	Ulcer (3), Cancer (1), Joint Pain (3), Uric acid (1)
78	*Dalbergia sissoo* Roxb. ex DC. [Fabaceae]; *Pramila-042*	*Sisoo*	T	Seed	Paste, Juice	Joint pain (3)
79	*Dalbergia stipulacea* Roxb. [Fabaceae]; *Pramila- 224*	*Chepte Biri*	T	Leaf, Root, Bark	Powder, Juice	Liver problem (3), Kidney problem (1), Urinary disorder (3), Respiratory problem (1)
80	*Dicliptera bupleuroides* Nees [Acanthaceae]; *Pramila- 104*		H	Root, Leaf	Decoction	Wounds healing (3), indigestions (2)
81	*Dimetia scandens* (Roxb.) R.J. Wang [Rubiaceae]; *Pramila- 166*	*Bakhrey Kane, baakhri lahara*	H	Root, Whole part	Juice	Loss of milk to cattle (4)
82	*Diospyros chloroxylon* Roxb. [Ebenaceae]; *Pramila- 318*	*kalikath*	T	Leaf	Paste	Burns (2)
83	*Diospyros montana* Roxb. [Ebenaceae]; *Pramila- 176*	*Anyu Kath, Anhu Kath*	T	Bark, Leaf, Stem	Decoction	Urinary Stones (3), Desentery (5)
84	*Diploknema butyracea* (Roxb.) H.J. Lam. [Sapotaceae]; *Pramila- 242*	*Chiudi, Chiuri*	T	Bark, Fruit	Juice	Indigestion (6), Eye problem (2)
85	*Docynia indica* (Colebr. ex Wall.) Decne. [Rosaceae]; *Pramila-361*	*Mehel*	T	Fruit	Dry fruit, decoction	Desentery (7)
86	*Drymaria diandra* Blume [Caryophyllaceae]; *Pramila- 164*	*Abijalo*	H	Whole plant	Extraction	Cold (2), Throat problem (2)
87	*Duabanga grandiflora* (Roxb. ex DC.) Walp. [Lythraceae]; *Pramila- 280*	*Lampate*	T	Leaf	Extraction	Joint pain (2), Stomachache (2), Skin disease (1)
88	*Duhaldea cappa* (Buch.-Ham. ex D. Don) Pruski & Anderb. [Asteraceae]; *Pramila-037*	*Gaaitihaare*	S	Root, Bark	Extraction	Dysentery (4)
89	*Eclipta prostrata* (L.) L. [Asteraceae]; *Pramila-191*	*Bhringaraaj*	H	Whole plant	Juice	Cuts and Wounds (5)
90	*Elatostema platyphyllum* Wedd. [Urticaceae]; *Pramila- 222*		H	Root	Juice	Vomiting (3)
91	*Eleusine indica* (L.) Gaertn. [Poaceae]; *Pramila-254*	*Kodejhar*	H	Seed	Paste	Skin diseases (2)
92	*Elsholtzia blanda* (Benth.) Benth. [Lamiaceae]; *Pramila-002*	*Bansilaam*	H	Seed	Juice	Stomachache (3), High blood pressure (5), Diabetes (3)
93	*Emilia sonchifolia* (L.) DC. [Asteraceae]; *Pramila- 138*		H	Leaf	Powder	Stomach disorder (5)
94	*Engelhardia spicata* Lechen ex Blume [Juglandaceae]; *Pramila- 202*	*Mauwa, PahadeMahuwa*	T	Bark	Juice	Fatigue (9)
95	*Erigeron canadensis* L. [Asteraceae]; *Pramila-134*		H	Root, Leaf	Paste, Juice	Constipation (1) and Diarrhea (3)
96	*Erythrina stricta* Roxb. [Fabaceae]; *Pramila-354*	*Faledo, theki Kath*	T	Leaf	Juice	Vermifuge for cattle (14)
97	*Euphorbia hirta* L. [Euphorbiaceae]; *Pramila-282*	*DudheJhar, AankleKjhar*	H	Whole plant	Paste, Powder	Stone problen (4)

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98	*Eurya acuminate* DC. [Pentaphylacaceae]; *Pramila- 116*	*Jhingni*	T	Leaf, Stem	Power	Bacteria Infection (2)
99	*Evolvulus nummularius* (L.) L. [Convolvulaceae]; *Pramila-336*		H	Whole plant	Juice	Cuts (2), Wounds (1) and Burns (2)
100	*Falconeria insignis* Royle [Euphorbiaceae]; *Pramila- 253*	*Khirro, Indrajau, khirla, Tegemba*	T	Fruit, Bark	Juice, Decoction, Powder	High blood pressure (5), Gastric (4), Piles (2), Fish poison (3)
101	*Ficus hispida* L.f. [Moraceae]; *Pramila-347*	*Dumri*	S	Fruit	Latex	Tonsillitis (3)
102	*Ficus lacor* Buch.-Ham. [Moraceae]; *Pramila-362*	*Kavro*	T	Bark	Juice	Piles(2)
103	*Ficus neriifolia* Sm. [Moraceae]; *Pramila-376*	*Dudhelo, Dudhilo*	T	Bark	Juice	Loss of milk in cattle (25)
104	*Ficus racemosa* L. [Moraceae]; *Pramila-320*	*Dumri*	T	Leaf, Fruits, Bark	Juice	Piles (1), Dysentery (4)
105	*Ficus semicordata* Buch.-Ham ex Sm. [Moraceae]; *Pramila-355*	*Khaniu*	T	Bark	Powder	Loss of milk in mother (20)
106	*Flemingia strobilifera* (L.) W.T. Aiton [Fabaceae]; *Pramila- 284*	*Bhatwasi*	S	Root	Juice	Diarrhea (3) and dysentery (3)
107	*Floscopa scandens* Lour. [Commelinaceae]; *Pramila- 174*	*Simkanegh ans*	H	Whole plant		Eye sore (4)
108	*Gmelina arborea* Roxb. ex Sm. [Lamiaceae]; *Pramila-364*	*Khamari/ Gambari*	T	Leaf	Juice	Headache (4), Ulcer (1), Cough (6)
109	*Gnaphalium polycaulon* Pers. [Asteraceae]; *Pramila-061*	*Bukephool*	H	Whole plant	Paste	Toothache (3), Ulcer (1)
110	*Gonostegia hirta* (Blume) Miq. [Urticaceae]; *Pramila- 132*	*Chipleghan s*	H	Root	Paste	Cuts and wounds (3)
111	*Grona triflora* (L.) H. Ohashi & K.Ohashi [Fabaceae]; *Pramila-378*		H	Whole plant	Paste, Juice	Fever (1), Skin problem (2)
112	*Gynocardia odorata* R.Br. [Achariaceae]; *Pramila-387*	*Badar Gede, Badare, Badar fal*	T	Stem, Bark	Juice	Diabetes (3), ulcer (1), Inflammation (3)
113	*Hedychium ellipticum* Buch.-Ham. ex Sm. [Zingiberaceae]; *Pramila-337*		H	Root, Flower	Juice	Skin diseases (3)
114	*Hedyotis pruinosa* Wight & Arn. [Rubiaceae]; *Pramila-338*	*Piringo*	H	Whole plant	Juice	Stomach problem (3)
115	*Heynea trijuga* Roxb. ex Sims. [Meliaceae]; *Pramila-*365	*Akhataru wa*	T	Seed	Paste, Juice	Burns (2)
116	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G.Don [Apocynaceae]; *Pramila- 112*	*Indra jau, Khirro, Aulekhirr o*	T	Leaf, Bark	Juice	Diarrhea (5) and Dysentery (3)
117	*Holoptelea integrifolia* (Roxb.) Planch. [Ulmaceae]; *Pramila-366*	*Kharane*	T	Bark	Paste	Swelling (3)
118	*Homalium napaulense* (DC.) Benth. [Salicaceae]; *Pramila- 220*	*Falamekat h*	T	Leaf	Juice	Poison to Cattle (3)
119	*Hydrocotyle sibthorpioides* Lam. [Araliaceae]; *Pramila- 285*		H	Leaf	Paste, Extract	Asthma (3)
120	*Hygrophila auriculata* (Schumach.) Heine [Acanthaceae]; *Pramila- 286*	*Kanda*	H	Whole plant	Paste	Swelling (3)
121	*Imperata cylindrica* (L.) Raeusch. [Poaceae]; *Pramila- 287*	*Furkesiru, Sano Siru, Khar*	H	Whole plant	Juice	Ringworms (5), Diarrhea (6)
122	*Justicia adhatoda* L. [Acanthaceae]; *Pramila-030*	*Asuro, kalo Bhasak*	S	Leaf, Root	Juice	Asthma (1) , Fever (4)
123	*Koenigia mollis* (D.Don) T.M. Schust. & Reveal [Polygonaceae]; *Pramila-177*	*Thotne*	H	Tender shoot	Decoction	Diarrhea (2)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
124	*Lagerstroemia parviflora* Roxb. [Lythraceae]; *Pramila-012*	*Bot dhayero/ Hade*	T	Flower	Juice	Chronic abdominal pain (3), Intestinal Ring worm (2)
125	*Laggera alata* (D.Don) Sch.Bip. ex Oliv. [Asteraceae]; *Pramila-375*	*ManagreJhar*	S	Bark, Leaf	Juice	Inflammation (1), Jaundice (2), Bacterial diseases (1)
126	*Leea indica* (Burm.f.) Merr. [Vitaceae]; *Pramila-096*	*FusreGaleni*	S	Leaf	Juice	Cuts and Wounds (5)
127	*Leea macrophylla* Roxb. ex Hornem. [Vitaceae]; *Pramila- 153*	*Chillogaleni, Bhalegaleni*	S	Root	Paste	Skin diseases (3), Cuts (6)
128	*Leucomeris spectabilis* D.Don [Asteraceae]; *Pramila- 268*		S	Whole plant	Juice	Tonsillitis (2)
129	*Litsea monopetala* (Roxb.) Pers. [Lauraceae]; *Pramila- 201*	*Patmero, Kutmero, Ratmate*	T	Stem, Bark, Leaf	Juice	Fish poison (5)
130	*Macaranga indica* Wight **[**Euphorbiaceae]; *Pramila-095*	*Malato, Malata, Malaito, Parewapat*	T	Fruit	Juice	Veneral sores (3)
131	*Maesa macrophylla* (Wall.) A.DC. [Primulaceae]; *Pramila-022*	*Bhogate*	T	Root	Juice	Jaundice (6)
132	*Mallotus nudiflorus* (L.) Kulju & Welzen [Euphorbiaceae]; *Pramila- 237*	*Pithari*	T	Leaf, Bark, root, Fruit	Juice	Musslesstifness (3)
133	*Mallotus philippensis* (Lam.) Müll.Arg. [Euphorbiaceae]; *Pramila-039*	*Sindure*	T	Leaf, Fruit	Powder	Wound (3), Anthelmintic (6)
134	*Mangifera indica* L. [Anacardiaceae]; *Pramila-386*	*Aap*	T	Seed	Paste, Juice	Jaundice (3)
135	*Martynia annua* L. [Martyniaceae]; *Pramila-097*	*Gomukhi*	S	Leaf	Paste, Juice	Wounds (3) and Sore throat (2)
136	*Melastoma malabathricum* L. [Melastomataceae]; *Pramila- 289*	*Angeri/ Chulesi*	S	Whole plant	Juice	Wounds, Skin diseases
137	*Micromelum integerrimum* (Roxb. ex DC.) Wight & Arn. ex Voigt [Rutaceae]; *Pramila- 255*		T	Leaf, Root	Juice	Infected wounds (4)
138	*Mikania micrantha* Kunth [Asteraceae]; *Pramila-059*	*Laharebanmara, Titelahara*	H	Whole plant	Juice	Microbial infection (2)
139	*Miliusa velutina* (DC.) Hook.f. & Thomson [Annonaceae]; *Pramila-205*	*Kali kath*	T	Bark	Paste, Juice	Bacteria Infection (2)
140	*Millettia extensa* (Benth.) Benth. ex Baker [Fabaceae]; *Pramila- 091*	*Tatari, Gaujo*	S	Bark	Paste	Wounds (2)
141	*Mimosa pudica* L. [Fabaceae]; *Pramila-051*		H	Leaf, Root	Juice, Paste	Urinary disorder (4), cuts and Wounds (3), Fever (3)
142	*Neolamarckia cadamba* (Roxb.) Bosser [Rubiaceae]; *Pramila-290*	*Kadam*	T	Leaf	Paste or Juice	Toothache (6)
143	*Nyctanthes arbor-tristis* L. [Oleaceae]; *Pramila-383*	*Parijaat*	S	Leaf	Decoction	Fever (4), Constipation (3)
144	*Oroxylum indicum* (L.) Kurz **[**Bignoniaceae]; *Pramila-088*	*Tatelo, Totalo*	T	Bark	Paste, Juice	Jaundice (3)
145	*Orthosiphon incurvus* Benth. [Lamiaceae]; *Pramila-078*		H	Whole plant	Juice	Diabetes (2)
146	*Osbeckia stellata* Buch.-Ham. ex D.Don [Melastomataceae]; *Pramila- 107*	*Ashare Phool*	S	Leaf	Paste	Ringworm (5)
147	*Ostodes paniculata* Blume [Euphorbiaceae]; *Pramila- 118*	*Bepaari*	T	Leaf, Fruit	Juice	Loss of milk in mother (6)
148	*Ototropis conferta* (DC.) H. Ohashi & K. Ohashi [Fabaceae]; *Pramila-346*	*Bhatte*	S	Bark	Juice	Diarrhea (4)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
149	*Ougeinia oojeninensis* (Roxb.) Hochr. [Fabaceae]; *Pramila-380*	*Sandan*	T	Bark	Paste	Cuts and wounds (5)
150	*Oxalis corniculata* L. [Oxalidaceae]; *Pramila-070*	*Chariamilo*	H	Whole plant	Paste	Inflammatory (2), Bodyache (6)
151	*Paederia foetida* L. [Rubiaceae]; *Pramila- 247*		H	Whole plant	Juice	Jaundice (2), Dysentery (1), Toothache (1)
152	*Paramignya monophylla* Wight [Rutaceae]; *Pramila- 262*		S	Root	Paste, Juice	Urinary (1) and Abdominal Problem (2)
153	*Peperomia pellucida* (L.) Kunth [Piperaceae]; *Pramila- 123*	*tapate*	H	Stem, Leaf	Juice	Eye inflammation (4)
154	*Persicaria capitata* (Buch.-Ham. ex D. Don) H.Gross [Polygonaceae]; *Pramila- 211*	*pire*	H	Whole plant	Paste	Wounds (2)and Burns (3)
155	*Persicaria pubescens* (Blume) H. Hara [Polygonaceae]; *Pramila-069*	*Pire*	H	Whole plant	Juice	Fish poisoning (7)
156	*Phanera vahlii* (Wight & Arn.) Benth. [Fabaceae]; *Pramila-381*	*Bhorla*	T	Root	Paste, Powder	Gastric problem (5), Stomach disorder (2), Constipation (2)
157	*Phyllanthus amarus* Schumach. & Thonn. [Phyllanthaceae]; *Pramila-340*	*Bhuiamala, AmalaJhar*	H	Leaf	Decoction	Diarrhea (3), Stomach disorder (2)
158	*Phyllanthus emblica* L. [Phyllanthaceae]; *Pramila-080*	*Amala, JungaliAmala, Ban Amala*	T	Fruit	Power, Juice	Cough (20), Gastric (5), Diarrhea (6)and Dysentery (4)
159	*Phyllanthus virgatus* G. Forst. [Phyllanthaceae]; *Pramila- 292*	*Bhuiamala*	H	Whole plant	Juice, Decoction	Eye inflammation (2), Urinary problem (2)
160	*Piper longum* L. [Piperaceae]; Pramila- 293	*Pipli*	H	Leaf, Fruit	Juice, Powder	Tuberculosis (8), Asthma (4)
161	*Pleurolobus gangeticus* (L.) J.St.-Hil. ex H.Ohashi & K.Ohashi [Fabaceae]; *Pramila-294*		H	Root	Paste	Snake bite (3)
162	*Pogonatherum crinitum* (Thunb.) Kunth [Poaceae]; *Pramila- 146*	*kharukoghans*	H	Whole plant	Paste	Coughing (1), Jaundice (3)
163	*Pogostemon amaranthoides* Benth. [Lamiaceae]; *Pramila- 103*	*Rudila*	H	Root	Juice	Headache (6)
164	*Pogostemon benghalensis* (Burm.f.) Kuntze [Lamiaceae]; *Pramila-023*	*Runche, Rudilo*	H	Root	Decoction	Cold (2), Cough (1) and dysentery (2)
165	*Pouzolzia rugulosa* (Wedd.) Acharya & Kravtsova [Urticaceae]; *Pramila- 106*	*Panidar*	T	Bark	Paste	Muscular swelling (3)
166	*Pouzolzia zeylanica* (L.) Benn. [Urticaceae]; *Pramila- 160*	*Chiplejhar*	H	Root	Paste	Bone fracture and dislocation (4)
167	*Prasoxylon excelsum* (Spreng.) Mabb. [Meliaceae]; *Pramila- 221*	*Lasune, ThuloDhamina,*	T	Young Shoot	Decoction	Vaginal discharge (4)
168	*Premna mollissima* Roth [Lamiaceae]; *Pramila- 295*	*Gineri*	T	Leaf, Root, Bark, Whole plant	Decoction	Fever (5), Jaundice (3)
169	*Pseudognaphalium adnatum* (DC.) Y.S. Chen [Asteraceae]; *Pramila- 323*	*Bookiphool*	H	Leaf, Flower	Paste, Juice	Diuretice (3), Food poisoning (2)
170	*Pseudognaphalium affine* (D.Don) Anderb. [Asteraceae]; *Pramila-032*	*Kairojhar, Bukephul*	H	Leaf, Flower	Paste	Cuts and Wounds (3)
171	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L.Burtt [Asteraceae]; *Pramila- 296*		H	Leaf	Juice	Diuretic (2), Astringent (3)
172	*Pterospermum acerifolium* (L.) Willd. [Malvaceae]; *Pramila-369*	*Hatti Pailey*	T	Flower	Paste	Inflammation (1), Blood troubles (2)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
173	*Pterygota alata* (Roxb.) R.Br. [Malvaceae]; *Pramila- 313*	*Byapari*	T	Bark, Root	juice	Poison to Cattle (7)
174	*Rauvolfia serpentina* (L.) Benth. ex Kurz [Apocynaceae]; *Pramila- 197*	*Chandamaruwa, Sarpagandha*	S	Root	Powder, Juice	Blood pressure (5), Diabetes (6), High blood pressure (4)
175	*Reinwardtia indica* Dumort. [Linaceae]; *Pramila-040*	*Pyaul*	S	Root	Paste	Headache (3)
176	*Rostellularia obtusa* Nees [Acanthaceae]; *Pramila-081*		H	Root	Juice	Typhoid (3)
177	*Rotheca serrata* (L.) Steane & Mabb. [Lamiaceae]; *Pramila-090*	*Andhiki, Bharagi*	S	Juice	Paste or Juice	Fever (2), Skin problem (2)
178	*Rubia manjith* Roxb. [Rubiaceae]; *Pramila-327*	*Majitho*	H	Root	Juice	Cuts and Wounds (5)
179	*Rubus ellipticus* Sm. [Rosaceae]; *Pramila-031*	*Ainselu*	S	Root, Fruit	Paste and Raw	Gastric problem (9), Urinary problem (3), Joint pain (3)
180	*Rungia himalayensis* C.B. Clarke [Acanthaceae]; *Pramila-038*	*Ukuchijhar*	H	Whole plant	Decoction	Cough (3)
181	*Rungia pectinata* (L.) Nees [Acanthaceae]; *Pramila-077*		H	Whole plant	Juice	Cuts and Wounds (5)
182	*Sambucus javanica* subsp. *chinensis* (Lindl.) Fukuoka [Adoxaceae]; *Pramila- 297*	*Galeni*	S	Fruit	Raw	Fever (3)
183	*Sapindus mukorossi* Gaertn. [Sapindaceae]; *Pramila-385*	*Rittha*	T	Bark, Fruit	Paste	Cough (3)
184	*Sarcococca coriacea* (Hook.) Sweet [Buxaceae]; *Pramila-072*	*Pinina, Sano Pipina, Pepari*	S	Bark	Juice	Fever (5)
185	*Saurauia napaulensis* DC. [Actinidiaceae]; *Pramila-66*	*Gogan*	T	Bark	Juice	Fever (7)
186	*Schima wallichii* (DC.) Korth. [Theaceae]; *Pramila-009*	*Chilaune, Aulechilaune*	T	Bark	Juice	Gastric (7)
187	*Scoparia dulcis* L. [Plantaginaceae]; *Pramila-298*	*ChiniJhar, Mithighans*	H	Leaf, Whole plant	Juice	Bodyache (4)
188	*Scutellaria scandens* D.Don [Lamiaceae]; *Pramila- 178*		H	Leaf	Juice	Cuts and Wounds (4)
189	*Semecarpus anacardium* L.f. [Anacardiaceae]; *Pramila-098*	*Bhalayo, Bhela, Kage Bhalayo*	T	Seed, Fruit	Powder	Skin diseases (3), Wounds (2)
190	*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb. [Fabaceae]; *Pramila-093*	*Khayar*	T	Stem	Decoction	Body pain (2), Blood purifier (3)
191	*Senegalia intsia* (L.) Maslin, Seigler & Ebinger [Fabaceae]; *Pramila- 309*	*Samakhori, Samakhora*	S	Root, Leaf, Bark	Paste, Juice	Diarrhea (2), Anthelmintic (3), Fish poison (4)
192	*Shorea robusta* C.F. Gaertn. [Dipterocarpaceae]; *Pramila- 259*	*Sakhuwa, Sal*	T	Stem	Decoction, juice	Dysentery (3), Piles (5)
193	*Sida acuta* Burm.f. [Malvaceae]; *Pramila- 194*		H	Whole plant	Juice	Indigestion (3)
194	*Sida cordata* (Burm.f.) Borss.Waalk. [Malvaceae]; *Pramila-055*		H	Whole plant	Juice	Wounds (8)
195	*Sida rhombifolia* L. [Malvaceae]; *Pramila- 152*		H	Root	Paste	Toothache (6)
196	*Smilax aspera* L. [Smilacaceae]; *Pramila-062*	*Kukurdana, Kukurdaino*	H	Rhizome	Paste, Juice	Skin diseases (4)
197	*Solanum nigrum* L. [Solanaceae]; *Pramila- 299*	*Kalo bihi*	H	Fruit	Chewed	Cough (4)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
198	*Solanum viarum* Dunal [Solanaceae]; *Pramila-199*	*Ban bhanta*	S	Fruit	Juice	Cough (4), Toothache (7)
199	*Solanum virginianum* L. [Solanaceae]; *Pramila-235*	*Bihi, Kantakari*	H	Root	Juice	Urinary trouble (2)
200	*Sonchus asper* (L.) Hill [Asteraceae]; *Pramila-341*		H	Whole plant	Paste	Wounds (4) and Burns (3)
201	*Spatholobus parviflorus* (Roxb. ex G.Don) Kuntze [Fabaceae]; *Pramila-384*	*Debre Lahara*	S	Stem, Root	Paste	Menstruation (4)
202	*Spermacoce alata* Aubl. [Rubiaceae]; *Pramila-100*	*Paudhi*	H	Whole plant	Juice	Microbial infection (2)
203	*Spermadictyon suaveolens* Roxb. [Rubiaceae]; *Pramila-001*	*Ban Champa*	S	Bark, Leaf	Decoction	Fever (2) and indigestion (2)
204	*Spondias pinnata* (L.f.) Kurz [Anacardiaceae]; *Pramila-370*	*Amaro*	T	Fruit	Raw	Tonsillitis (2), Asthma (1)
205	*Sterculia villosa* Roxb. ex Sm. [Malvaceae]; *Pramila-371*	*Odal, Odane, Seto Odal*	T	Leaf, Root	Juice, Powder	Urinary disorder (5), Stone problem (3)
206	*Streblus asper* Lour. [Moraceae]; *Pramila- 243*	*Khaksi, Dativan*	T	Leaf, shoot	Paste	Toothache (5), High blood pressure (1)
207	*Strobilanthes capitata* (Nees) T. Anderson [Acanthaceae]; *Pramila- 241*		H	Leaf, Root	Juice	Skin diseases (3), Inflammation (1)
208	*Synedrella nodiflora* (L.) Gaertn. [Asteraceae]; *Pramila- 135*		H	Leaf, Stem	Paste	Skin problems (3)
209	*Syzygium cumini* (L.) Skeels [Myrtaceae]; *Pramila- 50*	*Jamun, Jamuna*	T	Fruit	Juice, Raw	Diabetes (11)
210	*Syzygium nervosum* A. Cunn. ex DC. [Myrtaceae]; *Pramila-372*	*Kyamuna, Phulepa, Phandir, Fadir*	T	Bark	Paste, Powder	Headache (3)
211	*Tamarindus indica* L. [Fabaceae]; *Pramila-303*	*Titri*	T	Fruit	Raw, paste	Diabetes (1), Blood purifier (3), Blood circulation (3)
212	*Terminalia bellirica* (Gaertn.) Roxb. [Combretaceae]; *Pramila-82*	*Barro*	T	Friut	Powder	Cold and Cough (15), Indigestion (6)and Constipation (3)
213	*Terminalia chebula* Retz. [Combretaceae]; *Pramila-043*	*Harro*	T	Friut	Powder	Jaundice (5), Indigestion (8), Constipation (5)
214	*Terminalia myriocarpa* Van Heurck & Müll.Arg. [Combretaceae]; *Pramila- 256*	*PaniSaj*	T	Bark	Juice	Cuts and Wounds (8)
215	*Terminalia paniculata* Heyne ex Roth [Combretaceae]; *Pramila- 204*	*Saj, Asna*	T	Bark	Powder, Decoction	Jaundice (5), Gastric (4), High blood pressure (2)
216	*Tetradium fraxinifolium* (Hook.) T.G. Hartley [Rutaceae]; *Pramila-094*	*Bhabis*	T	Fruit	Juice	Gastric (3)
217	*Tetrastigma serrulatum* (Roxb.) Planch. [Vitaceae]; *Pramila-013*	*Charchare*	H	Whole plant	Paste	Bone dislocation (4)
218	*Thunbergia alata* Bojer ex Sims [Acanthaceae]; *Pramila- 223*	*Tite Lahara*	C	Leaf	Juice	Cuts and wounds (3)
219	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda [Poaceae]; *Pramila-49*	*Amriso, Amliso*	S	Whole plant	Extraction	Anthelmintic (3)
220	*Toona ciliata* M. Roem. [Meliaceae]; *Pramila-374*	*Tooni, Tuna, Tuni*	T	Bark, leaf	Juice	Toothache (5)
221	*Torenia crustacea* (L.) Cham. & Schltdl. [Linderniaceae]; *Pramila- 183*		H	Whole plant	Juice	Diabetes (3)
222	*Toxicodendron succedaneum* (L.) Kuntze [Anacardiaceae]; *Pramila- 209*	*PahadeBhalayo, ThuloBhalayo, Kage Bhalayo,*	T	Leaf	Juice	Diarrhea (6)

Sl. No.	Scientific name [Family]; Voucher no.	Local name	Habit	Parts used	Mode of Administration	Ailments & Nu. Of use reports
223	*Trema orientale* (L.) Blume [Cannabaceae]; *Pramila- 304*	*Khari, Kunyel*	T	Bark	Decoction	Diabetes (3)
224	*Tridax procumbens* L. [Asteraceae]; *Pramila-305*		H	Whole plant	Juice	Fever (3)
225	*Triumfetta pilosa* Roth [Malvaceae]; *Pramila-306*		H	Leaf, Flower	Paste	Leprosy (2)
226	*Uncaria sessilifructus* Roxb. [Rubiaceae]; *Pramila- 24*	*Bhaisi Kanda*	C	Whole plant	Juice	Bodyache (4), Joint pain (5), Uric acid problem (3)
227	*Urena lobata* L. [Malvaceae]; *Pramila- 203*	*Bhede Kuro*	H	Leaf	Juice	Wounds (6)
228	*Urtica dioica* L. [Urticaceae]; *Pramila- 307*	*Sisnu*	H	Leaf	Decoction, juice	High blood pressure (10), Constipation (5)
229	*Veronica javanica* Blume [Plantaginaceae]; *Pramila-342*		H	Whole plant	Juice	Skin diseases (5)
230	*Wendlandia heynei* (Schult.) Santapau & Merchant [Rubiaceae]; *Pramila- 316*	*Tilake*	T	Leaf	Powder	Wounds (2) and Skin diseases (3)
231	*Woodfordia fruticosa* (L.) Kurz [Lythraceae]; *Pramila- 315*	*Dhaiyaro, Dhuinya, Amar Phool, Dhayaro*	S	Leaf, Flower	Decoction	Fever (7)
232	*Wrightia arborea* (Dennst.) Mabb. [Apocynaceae]; *Pramila-83*	*Rani Khirro*	T	Stem, Root	Juice	Snake bites (1) and scorpion sting (3)
233	*Youngia japonica* (L.) DC. [Asteraceae]; *Pramila- 308*	*Chaulane*	H	Leaf, Fruit	Juice	Toothache (2)
234	*Zanthoxylum armatum* DC. [Rutaceae]; *Pramila-356*	*Timur*	T	Seed	Paste	Stomach disorder (4), Gastric (6)
235	*Ziziphus jujuba* Mill. [Rhamnaceae]; *Pramila-052*	*Bayer*	T	Fruit, Bark	Juice	Skin diseases (Small pox) (3)

The highly reported families for treating various ailments were Fabaceae (150), Asteraceae (139), Lamiaceae (76), Malvaceae (71), Combretaceae (66), Moraceae (61), Rutaceae (53), Phyllanthaceae (50), Rubiaceae (49) Euphorbiaceae (45), and Poaceae (36) (Table 4). However, Lamiaceae was found to be the leading family by Sulaiman *et al.* (2020). The therapeutic dominancy of Fabaceae and Asteraceae is associated with their wide and common distribution in Nepal and adjoining areas (Singh & Lal 2008; Thapa 2012; Wali *et al.* 2019; Babu *et al.* 2019; Budha-magar & Bhandari 2020a). Considering the habit-groups, herbs were the dominant (44 %) followed by trees (34 %), shrubs (21 %) and climbers (1 %) (Figure 3). Studies from Nepal and its neighbouring countries also reported herbs are predominant among medicinal plants (Bhattarai *et al.* 2010; Uprety *et al.* 2010; Kunwar *et al.* 2015; Ghimire *et al.* 2018).

Table 4. Numerical diversity of medicinal plants and their species and family levels in the study area

		Species		Genus			
S.N.	**Family**	**No.**	**%**	**No.**	**%**	**FC**	**FIV**
1	Acanthaceae	10	3.89	8	3.69	39	78
2	Achariaceae	1	0.39	1	0.46	7	14
3	Actinidiaceae	1	0.39	1	0.46	7	14
4	Adoxaceae	1	0.39	1	0.46	3	6
5	Amaranthaceae	3	1.17	2	0.92	15	30
6	Anacardiaceae	5	1.95	5	2.30	24	48

		Species		Genus			
S.N.	**Family**	**No.**	**%**	**No.**	**%**	**FC**	**FIV**
7	Annonaceae	1	0.39	1	0.46	2	4
8	Apiaceae	1	0.39	1	0.46	9	18
9	Apocynaceae	5	1.95	5	2.30	44	88
10	Araceae	2	0.78	2	0.92	6	12
11	Araliaceae	1	0.39	1	0.46	3	6
12	Arecaceae	1	0.39	1	0.46	3	6
13	Asteraceae	29	11.28	25	11.52	139	278
14	Begoniaceae	1	0.39	1	0.46	2	4
15	Berberidaceae	1	0.39	1	0.46	3	6
16	Betuliaceae	1	0.39	1	0.46	8	16
17	Bignoniaceae	1	0.39	1	0.46	3	6
18	Buxaceae	1	0.39	1	0.46	5	10
19	Cannabaceae	1	0.39	1	0.46	3	6
20	Caryophyllaceae	1	0.39	1	0.46	4	8
21	Celastraceae	1	0.39	1	0.46	2	4
22	Combretaceae	5	1.95	2	0.92	66	132
23	Commelinaceae	3	1.17	2	0.92	11	22
24	Convolvulaceae	2	0.78	2	0.92	7	14
25	Cornaceae	2	0.78	2	0.92	13	26
26	Cyperaceae	2	0.78	1	0.46	10	20
27	Dipterocarpaceae	1	0.39	1	0.46	8	16
28	Ebenaceae	2	0.78	1	0.46	10	20
29	Euphorbiaceae	7	2.72	6	2.76	44	88
30	Fabaceae	25	9.73	16	7.37	150	300
31	Hypoxidaceae	1	0.39	1	0.46	4	8
32	Juglandaceae	1	0.39	1	0.46	9	18
33	Lamiaceae	12	4.67	10	4.61	76	100
34	Lauraceae	3	1.17	3	1.38	27	54
35	Lecythidaceae	1	0.39	1	0.46	15	30
36	Linaceae	1	0.39	1	0.46	3	6
37	Linderniaceae	1	0.39	1	0.46	3	6
38	Lythraceae	3	1.17	3	1.38	17	34
39	Malvaceae	11	4.28	9	4.15	71	142
40	Martyniaceae	1	0.39	1	0.46	5	10
41	Melastomataceae	2	0.78	2	0.92	17	34

		Species		Genus			
S.N.	**Family**	**No.**	**%**	**No.**	**%**	**FC**	**FIV**
42	Meliaceae	4	1.56	4	1.84	13	26
43	Menispermaceae	1	0.39	1	0.46	4	8
44	Moraceae	6	2.33	2	0.92	61	122
45	Myrtaceae	2	0.78	1	0.46	14	28
46	Nyctaginaceae	1	0.39	1	0.46	5	10
47	Oleaceae	1	0.39	1	0.46	7	14
48	Oxalidaceae	2	0.78	2	0.92	11	22
49	Pentaphyllaceae	1	0.39	1	0.46	2	4
50	Phyllanthaceae	6	2.33	4	1.84	51	102
51	Piperaceae	2	0.78	2	0.92	16	32
52	Plantaginaceae	2	0.78	2	0.92	9	18
53	Poaceae	6	2.33	6	2.76	36	72
54	Polygonaceae	3	1.17	2	0.92	14	28
55	Primulaceae	1	0.39	1	0.46	6	12
56	Ranunculaceae	1	0.39	1	0.46	2	4
57	Rhamnaceae	1	0.39	1	0.46	3	6
58	Rosaceae	2	0.78	2	0.92	22	44
59	Rubiaceae	10	3.89	10	4.61	49	98
60	Rutaceae	7	2.72	7	3.23	53	106
61	Salicaceae	1	0.39	1	0.46	3	6
62	Sapindaceae	1	0.39	1	0.46	3	6
63	Sapotaceae	1	0.39	1	0.46	8	16
64	Smilacaceae	1	0.39	1	0.46	4	8
65	Solanaceae	4	1.56	2	0.92	29	58
66	Theaceae	1	0.39	1	0.46	7	14
67	Ulmaceae	1	0.39	1	0.46	3	6
68	Urticaceae	5	1.95	4	1.84	28	56
69	Verbenaceae	1	0.39	1	0.46	8	16
70	Vitaceae	3	1.17	2	0.92	18	36
71	Zingiberaceae	2	0.78	2	0.92	10	20
		235		195		1396	

Frequency of usage of plant parts in medicine

Data collected during the present study revealed on analysis that leaves (28%), roots (16%), barks and whole plants (15% each), fruits (10%), stems (6%), flowers (4%), and seeds (3%) were the preferred plant parts used in treating various diseases by the practitioners. Other plant parts, such as shoots, tendrils, latex, etc., were used only by 3 % of the respondents (Figure 4).

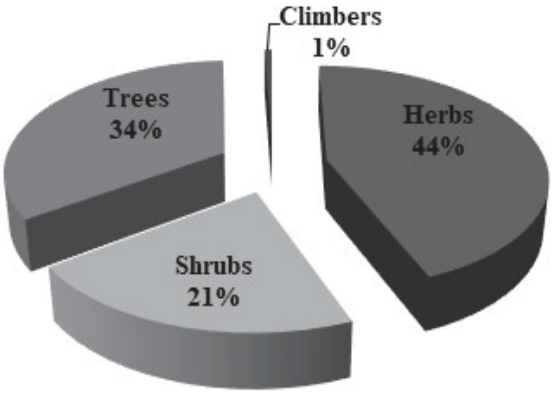

Figure 3. Representation for major habit-groups of recorded medicinal plants in the study area

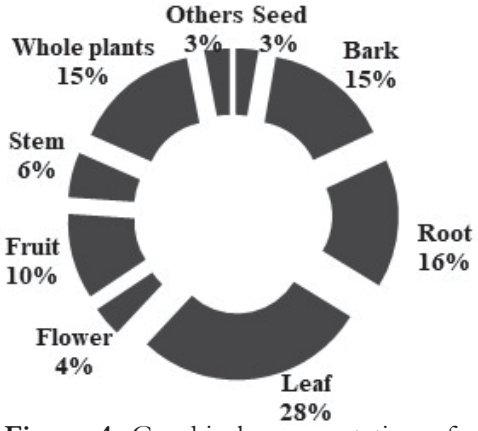

Figure 4. Graphical representation of different plants-parts used for traditional medicines in the study area

Mode of preparation and administration

Various modes of preparation of medicines have been recognized including paste (42 %), juice (18 %), decoction (16 %), powder (14 %), extraction (4 %), and others (6 %) (Figure 5). Raw fruits, vegetables, and oils were categorized under 'others' (Figure 4). Based on the nature of the ailments, the respondents administer prepared medicines either orally or externally/ topically. The analysis showed that medicinal plants were mostly used in the form of paste. The paste generally made of fresh materials using little water. They also use oil in some cases according to preference of healers. This result is similar to the findings of Bhattarai *et al.* (2010)

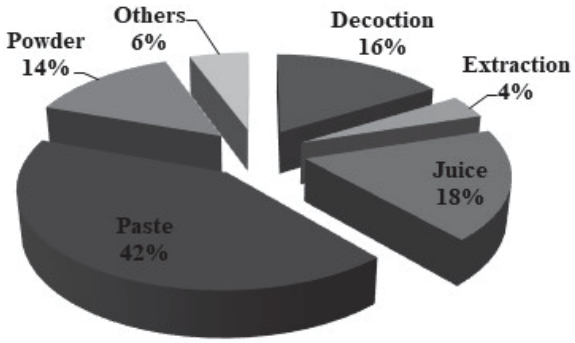

Figure 5. Mode of administration of prepared traditional medicines by the practitioners in the study area

and is contrast to the findings of Limbu and Rai (2013). Ambu *et al.* (2020) reported the use of freshly collected medicinal plants in juice form (36.27 %). It was observed that people use a single herb or combine many herbs to treat a variety of illnesses. The same case was reported by A*mbu e*t al. (2020) and Gachhadar (2006). It was observed that a single plant used for the treatment of different ailments. For example, *Paramignya monophylla* used for curing abdominal problem as well as urinary problems. Similarly, leaves of *Urtica dioica* is applied in constipation and high blood pressure. In the same way a single disease is cured by many medicinal plants such as, in skin diseases plants like *Strobilanthes capitata*, *Semecarpus anacardium*, *Chonemorpha fragrans*, *Synedrella nodiflora*, *Albizia lebbeck*, *Grona triflora*, *Rotheca serrata*, *Melastoma malabathricum*, etc are used by different practitioners (Table 3).

Usage report analysis based on the treatment of ailments

Traditional practices of plant use vary across regions and are influenced by factors such as location, climate, vegetation type, and local beliefs (Abadi & Shimels 2018; Kunwar & Bussmann 2008). In

Table 5. Informant Consensus Factor (IFC) by different categories of diseases

	Use category	Ailments	Frequency of usage/ use citation (Nur)	No. of species used (Nt)	Informant Consensus Factor (ICF)
1	Kidney problems		1	1	0
2	Cancer problems		2	2	0
3	Hair care	Dandruff, Hair loss	6	6	0
4	Infectious diseases	Leprosy, Microbial infections, bacterial infections	11	8	0.3
5	Poisonous bites	Snake and scorpion bite	4	3	0.33
6	Cardiovascular diseases	Blood circulation problem, high blood pressure, toxic blood problems	63	26	0.60
7	Bone diseases	Bone fracture and bone dislocation	12	5	0.64
8	Urinogenital and reproductive disorders	Prostrate problem, Urinary Stone problem, Uric acid problem, Urinary disorder, Veginal discharge, veneral sore, Menstruation	86	28	0.68
9	Liver problem	Jaundice, Liver problem	49	16	0.69
10	Skin infections	Skin diseases	56	18	0.69
11	Wound healing	Boils and burns, Cuts and wounds, Wounds, Wounds (leg wounds made by mud in rainy season) , Inflammation, Muscular swelling and muscles stiffness	239	67	0.72
12	Optical complications	Eye inflammation, Eye sore	12	4	0.73
13	High glucose level	Diabetes	49	13	0.75
14	Aches	Joint pain, Toothache	66	16	0.77
15	Respiratory system illness	Common cold, Cough, Respiratory problem, bronchitis, tonsillitis, sore throat, throat problem, Tuberculosis, asthma	192	40	0.80
16	Gastrointestinal diseases	Constipation, Diarrhea, Dysentery, Fish poison, Food poison, Gastric, Intestinal Ring worm, Indigestion, Stomach disorder (Chronic abdominal pain), Piles, Poison to cattle, Indigestion, Ulcer, Vermifuge, Vomiting	545	110	0.80
17	General health	Body pain, fever, typhoid, fatigue, Headache, Loss of appetite, Loss of milk in mother (Human and cattles)	161	32	0.8

the study area, 63 various ailments as mentioned above were treated using the documented medicinal plants. These ailments have been grouped into 17 usage categories. The total number of reports on the usage of medicinal plants for various ailments documented in this study was 1396 (Table 4). Among the illness categories, gastrointestinal diseases had the highest usage report (545) with a large number of species, followed by wound healing (239), respiratory problems/ disorders (192), and general health care (161), among others, as shown in Table 5.

Frequency of Citation

Among the total number of user reports cited, *Phyllanthus emblica* (35 FC) had the highest frequency of citation, followed by *Ficus neriifolia* (25 FC), *Terminalia bellirica* (24 FC), *Artemisia indica* (23 FC), *Aegle marmelos* (22 FC), and so on (Table 3).

Relative Frequency of Citation

The Relative Frequency of Citation (RFC) for medicinal plants' ability to heal ailments ranged from 0.02 to 0.7 (Table 3). The informants reported a total of 235 plant species for various treatment purposes, with *Phyllanthus emblica* having the highest RFC value of 0.7 and *Bridelia retusa* the lowest. The fruits of *Phyllanthus emblica* were used to treat diarrhea, dysentery, gastric issues, and cough. *Ficus neriifolia* had the next highest RFC value of 0.5, and it was used for its medicinal value in secreting milk for cattle. In the present study, the use report value varied from 1 to 35. The most used plant species were *Phyllanthus emblica*, *Ficus neriifolia*, *Terminalia bellirica, Artemisia indica, Aegle marmelos, Ficus semicordata, Terminalia chebula, Cinnamomum tamala, Urtica dioica, Rubus ellipticus, Rauvolfia serpentina, Careya arborea*, and *Bombax ceiba*.

Informant Consensus Factors (ICF)

The Informant Consensus Factor (ICF) was calculated by categorizing reported ailments into 17 use categories along with the number of user reports and number of species (Table 5). In this study, the range of ICF values recorded was from 0 to 0.88. The ICF measures the consistency of participants' knowledge regarding the use of various plant species to treat different ailment categories (Gazzaneo *et al.* 2005). ICF values near to one indicated a high homogeneity of knowledge among the informants. The highest ICF values were reported for general health ailment category followed by gastrointestinal diseases, and respiratory system illnesses, each with ICF values of 0.8, and so on. Gastrointestinal diseases dominated among the ailment categories with 545 use reports, followed by wound healing, general health disorders, urino-genital and reproductive disorders, aches problems, and others, with 239, 192, 161, 86, and 66 use reports, respectively (Table 5).The analysis showed that 110 plant species were used to treat gastrointestinal diseases, followed by wound healing (67 spp.), respiratory system illnesses (40 spp.), general health disorders (32 spp.), urino-genital and reproductive system ailments (28 spp.), cardiovascular diseases (26 spp.), and others. The results showed that gastrointestinal diseases and wound healing were particularly common in the study area, similar to previous studies (Sulaiman *et al.* 2020; Laldingliani *et al.* 2022). Malnutrition, poor sanitation, an irregular diet, and tainted water were likely responsible for the occurrence of high frequency of gastrointestinal diseases (Luitel *et al.* 2014; Miftahussurur *et al.* 2015; Abbas *et al.* 2017).

Moreover, the high ICF values for the General health, Gastrointestinal diseases and Respiratory system illness categories indicated high level of consensus among the informants regarding the effectiveness of traditional medicinal plants for treating health issues. This underscores the importance of traditional medicinal knowledge in the local culture and highlights the potential for further research on traditional medicine to benefit public health.

Furthermore, the identification of specific plant species that are commonly used for treating various ailments has important implications for the conservation and sustainable use of medicinal plants in the study area. Targeted conservation efforts and the development of appropriate management strategies can help to ensure that these plant species are available for future generations to use and benefit from.

Conclusions

In the study area, local people were found using 235 plant taxa belonging to 71 families for curative purposes. These plants were used for the treatment of many diseases, which were categorized into 17 use groups here in this paper. Majority of plants were dried and used as decoctions and powder by the locals throughout the year. Most commonly used plants were *Phyllanthes emblica,* and most commonly used parts of the plants were the leaves. Numerous plants were used to cure a variety of diseases, including high blood pressure, stomach disorder, digestive disorders, cuts and wound healing, fever, menstrual disorder, skin diseases and many more diseases. The same plant was named differently by local people and different species were called by the same name.

Elderly people and healers were found more informative and knowledgeable about medical treatments and utilization patterns of them. They have a high potential information about the different ways that plant resources might be used. Majority of elderly people in the research area were found receiving their first level healthcare from medicinal plants or after getting disappointed by allopathic medicine. Due to numerous human-related activities such as deforestation, habitat destruction, irresponsible collection of forest products, over harvesting etc. are serious threatening drivers of medicinal plants in the study area. Additionally, the indigenous knowledge of the people is in great danger of loss as a result of many ecological, social, and economic causes.

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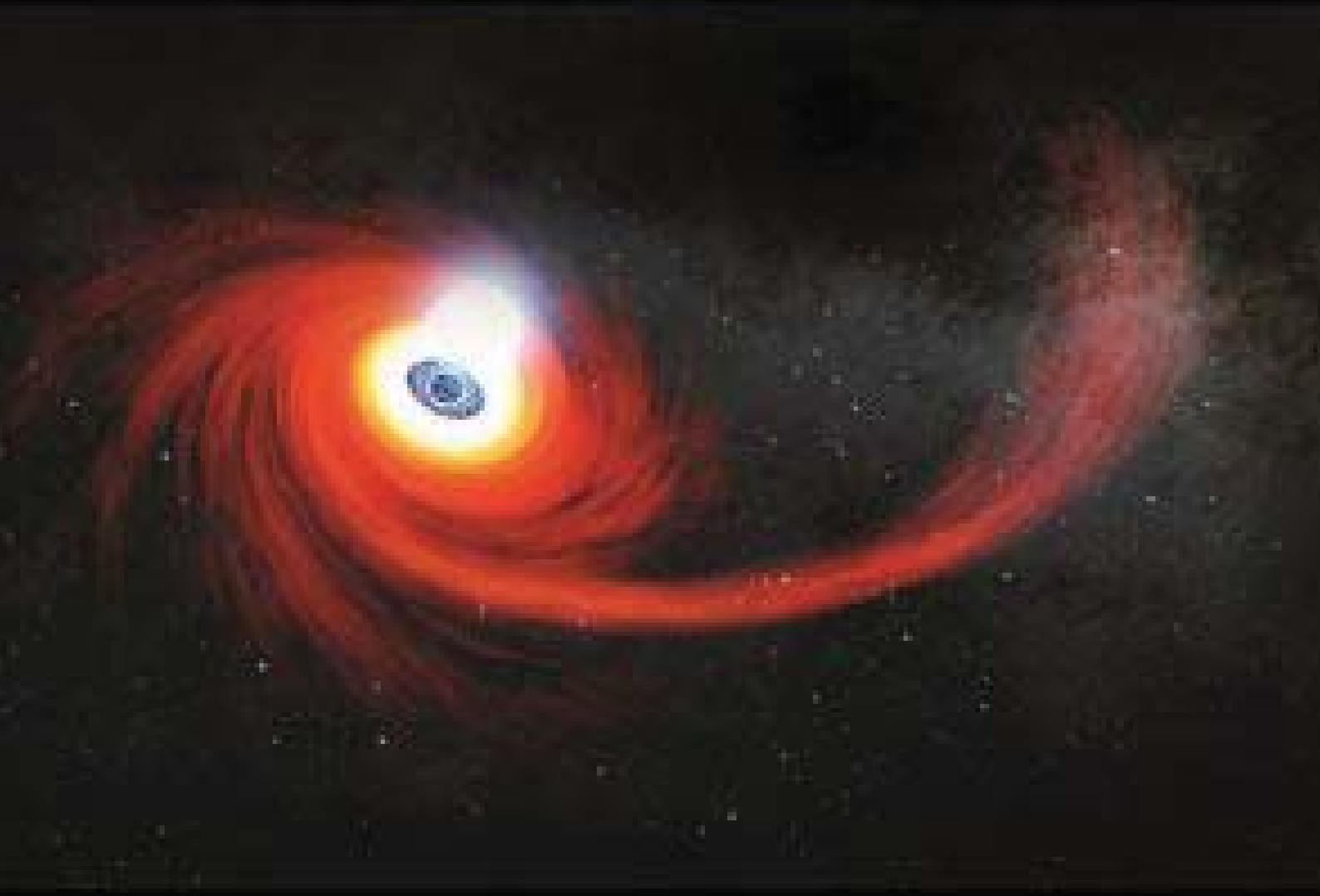

Forest structure and biodiversity patterns along elevational gradients in Eastern Nepal

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Abstract: This study aimed to assess the forest structure, composition, and diversity pattern at different elevations in Morang District, eastern Nepal, using stratified random vegetation sampling technique in five forests: Bhaunne, Raja-Rani, Murchungi, Adheri, and Sagma. Trees, shrubs and herbs of each forest was sampled through quadrat of 20 × 20 m^2, 5 × 5 m^2, and 1 × 1 m^2 each respectively. A total of 315 plant species belonging to 82 families and 255 genera found by this study. A total of 50 quadrats each for trees, shrubs and herbs sampled during this study. A total 10 quadrats studied for each life form from each forest. This study obtained 5,037 individuals across all forests. The highest number of species (55) was recorded from Raja Rani forest, and the highest tree density (985 ind ha^{-1}) was observed in Adheri forest. The highest density of shrub (24400 ind. ha^{-1}) and herbs (44.1 $ind.m^{-2}$) were recorded in Sagma forest. The Shannon Wiener index value of herb layer was found to be the highest (3.79) at Bhaunne forest. This value for shrub layer was 2.98 and tree layer was 3.12 at Sagma which was the maximum among forests. The concentrations of dominance value were high for herb and shrub layer in Bhaunne forest, and it was maximum for the tree layer in Adheri forest. The forest species composition were significantly different ($p \leq 0.001$) among each other. Total basal area of shrub layer and tree layer recorded were maximum (111.52 m^2 ha^{-1} and 612.08 m^2 ha^{-1}) in Sagma and Adheri forest, respectively. The number of trees decreased with increasing elevation, while shrubs increased, and herbs showed a U-shaped trend. The dominant tree species were *Senegalia catechu*, *Shorea robusta*, *Terminalia alata*, and *Schima wallichii* in Bhaunne, Raja-Rani, Murchungi, and Sagma forest, respectively, with *Shorea robusta* being dominant in Adheri forest. These findings have important implications for forest management and conservation efforts in the region.

Keywords: Diversity; Community structure; Dominance; Niche; Tropics; Species Richness.

Introduction

The structure and biodiversity of forests along elevational gradients in Eastern Nepal hold immense significance for understanding and conserving terrestrial ecosystems[1]. Forests are characterized by their complex assemblage of plant species. Plant species play a crucial role in maintaining the overall biodiversity and ensuring the stability and functionality of ecosystems[2, 3]. The study of forest structure and biodiversity patterns along elevational gradients provides valuable insights into the organization, composition, and dynamics of these ecosystems, offering a foundation for effective conservation and management strategies[4].

Forest structure encompasses the physical characteristics and arrangement of trees and other vegetation components within a forest ecosystem. It includes elements such as tree density, canopy cover, tree size distribution, and vertical stratification. The structural attributes of forests influences ecological processes, habitat availability, and ecosystem functioning.[5] By examining forest structure, researchers can gain insights into the resilience and adaptability of forests to changing environmental conditions, as well as their ability to provide ecosystem services such as carbon sequestration, soil stabilization, and water regulation[6,7,8]. Biodiversity patterns, on the other hand, capture the distribution and abundance of plant species across

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different elevations[7,9]. Elevational gradients in Eastern Nepal exhibit significant variations in climatic conditions, including temperature, rainfall, and soil properties. These gradients create distinct ecological niches and vegetation zones, resulting in diverse forest ecosystems. The study of biodiversity patterns along elevational gradients helps to elucidate the relationship between environmental factors and the distribution patterns of plant species, providing critical information for understanding ecosystem dynamics and guiding conservation efforts[10,11].

Eastern Nepal, with its diverse topography and climatic conditions, presents a unique opportunity to investigate forest structure and biodiversity patterns along elevational gradients[9]. The region encompasses a range of forest types, including tropical lowland forests, subtropical forests, temperate forests, and subalpine forests, each associated with specific elevational ranges[13,14,15]. However, these forests face numerous threats, including deforestation, habitat degradation, climate change impacts[16] etc. Therefore, it is essential to study the structure and biodiversity of these forests to guide conservation efforts, promote sustainable forest management, and ensure the long-term survival of these valuable ecosystems and human.

Species diversity is an important index in community ecology[17]. This research aims to comprehensively examine the forest structure and biodiversity patterns along elevational gradients in Eastern Nepal. The specific objectives of this research were: 1) to determine the plant community composition pattern among different forests, and 2) to know their taxonomic diversity.

By gaining a comprehensive understanding of forest structure and biodiversity patterns in Eastern Nepal, this research will contribute to the broader knowledge of forest ecology and provide valuable insights for conservation planning and management. The findings will help identify key conservation priorities, develop effective strategies for sustainable forest management, and contribute to the broader scientific understanding of forest dynamics and ecosystem functioning. Ultimately, this research holds significant implications for both scientific understanding and practical conservation initiatives in mountainous regions facing environmental challenges.

Materials and Methods

Study area

This study was conducted in five forests along an elevation (100–1300 m a.s.l.) in Morang District, east Nepal (Figure 1). The latitude and longitude of study area were ranged from 26°39'45.69"N to 26°48'28.68"N and 87°28'2.08"E to 87°28'45.06"E respectively. The five study sites: Bhaunne (B), Raja-Rani (R), Murchungi (M), Adheri (A) and Sagma (S) included the Belbari-Chisang Raja-Rani, Akashe, Shat Kanya and Kuwapani community forests respectively. Among these forest sites, Bhaunne is located at ward number 10 of Belbari Municipality and other four sites belonged to ward number-1 of Letang Municipality.

Figure 1: Map of the study area.

Climate of the studied forests

Studied area has prevalent monsoon climate with dry winters and rainy summers. From June through September, there is significant rainfall. Up to 1000 m above sea level, there is a hot monsoon climate with hot, wet summers and mild, warm, dry winters. Mean annual minimum temperatures ranged from 11°C to 25°C and mean annual maximum temperature ranged from 21°C to 35°C (Figure 2a). Mean annual rainfall ranged from 64.4 mm to 10630.12 mm (Figures 2a, b). All these forests were moist tropical forest. The elevation zone between

100 and 1000 m a.s.l. was commonly described as tropical zone. The forests were dominated by the tropical species such as *Shorea robusta* (Dipterocarpaceae), and subtropical species associated with the forests are *Adina cordifolia, Careya arborea, Dillenia pentagyna, Terminalia bellirica, Terminalia chebula, Lagerstroemia parviflora and Dalbergia sissoo*[13]. The 5th site, Sagma, however, lies above 1000 m above sea level, has a warm temperate monsoon climate with warm, wet summers and chilly, dry winters. The maximum annual rainfall (4908.6) was during July (Figure 2d). Mean annual minimum temperatures ranged between 7°C to 21°C and mean annual maximum temperature ranged from 20°C to 29°C (Figure 2c). It is dominated by *Schima wallichii*.

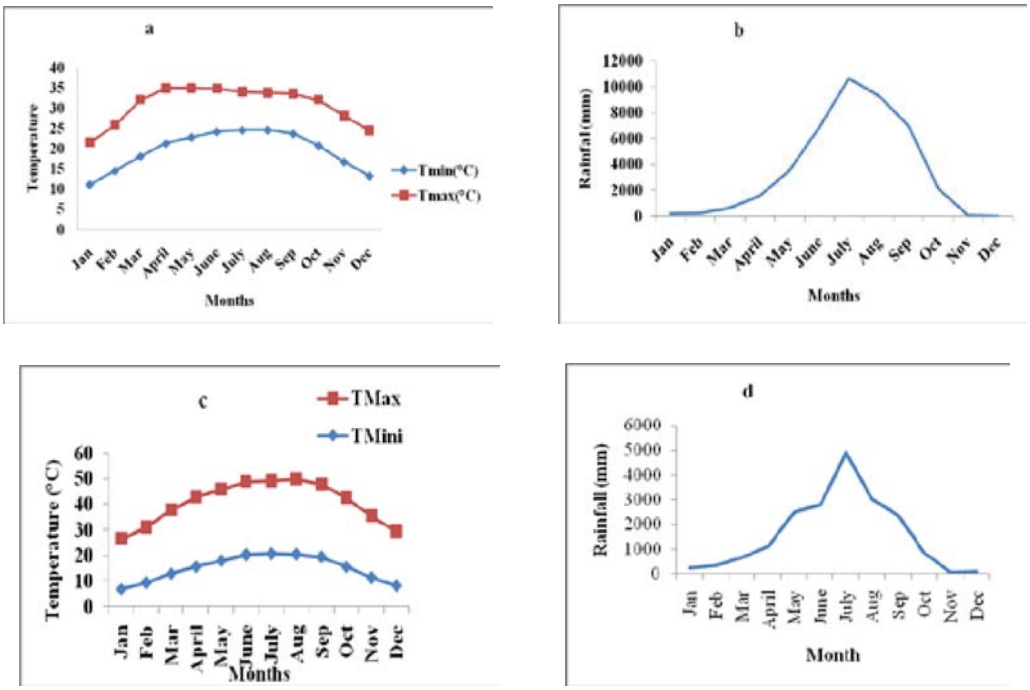

Figure 2: Summary of rainfall and temperature of the study area. 'a' & 'b' are monthly average minimum and maximum temperature and total rainfall in B, R, M and A forests; 'c' & 'd' represents average minimum & maximum temperature and rainfall in forest S.

Vegetation

Vegetation Sampling and data collection

Five forests: Baunne, Raja-Rani, Murchungi, Adheri and Sagma of Morang District, Koshi Province were selected as the study area. The elevation of these forests were ranged from 100 - 300 m a.s.l,, 380- 600 m a.s.l., 700- 880 m a.s.l, 900-1080 m a.s.l and 1100-1300 m a.s.l. respectively. Data on plant species composition were collected by setting up 20 m x 20 m sized quadrat for trees, 5 m x 5 m nested quadrat for shrubs and 1 m x 1 m nested quadrat for herbs. All trees, shrubs and herb species rooted inside each of their respective quadrat were recorded. Density of each plant species and their cover were recorded. Diameter at breast height (DBH) for all trees and shrubs inside each quadrat were recorded. Trees were defined as species having diameter ≥ 10 cm[18]. Similarly, girths at 10 cm above the ground level were measured for shrubs, whereas, for the herbs, each species were counted and weighted separately. Oven dried herbs again weighted to calculate their biomass. Total number of quadrats sampled were 50 (10 per site or forest). We measured the elevation and aspects by using a GPS (Garmin Colorado-300). Plant species occurring inside each quadrat was counted, tagged, collected for herbarium preparation and identification. Species not identified in the field were identified after consulting with experts and comparing with identified species that were deposited to the National Herbarium and Plant Laboratories, Godawari, Lalitpur of Nepal (KATH). Standard literature used for nomenclature[19,20,21]. Density and relative density, frequency and relative frequency, basal area and Importance Value Index (IVI) of each species for herbs,

shrubs and tree were calculated in each forest stand by following Kershaw and Looney[22]. Species diversity parameters like species richness, Shannon Wiener index, Equitability (evenness), and Simpson index were determined. Gathered data were analyzed by using Microsoft Excel and R Core Team [23].

Data analysis

Community composition among five forests were analyzed after following Permutational Multivariate Analysis of Variance using Distance matrices technique (ADONIS) in vegan package in R[24]. Sharing of species in different niches were analyzed through Venn diagram Package of R[24].

Diversity indices such as Shannon Wiener index, Equitability (evenness) index, and Simpson index, frequency, relative frequency, density, relative density, basal area and relative basal were calculated after using the standard formula[22].

Nomenclature

This research followed APG-III[25] system of plant taxonomic nomenclature and all latest names were checked through POWO-2023[21,26].

Results and Discussions

Species diversity

This study found a total of 315 plant species belonging to 82 families across all stands (Table 3). Among these species, the herbaceous life form made up the greatest percentage (45%) followed by trees (33%), and shrubs (22%) (Figure 3).

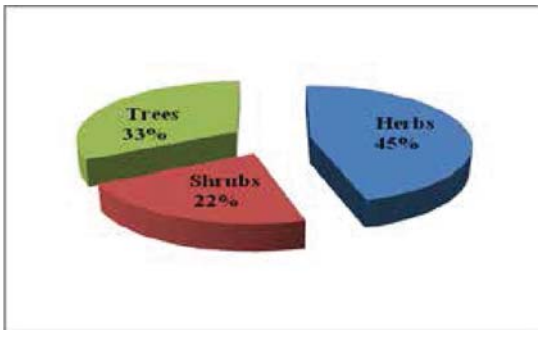

Figure 3: Percentage of plant habits throughout the study area

The total species richness was found decreased according to elevation of these forests. Total richness was found as 142, 126, 121, 121 and 137 species to Bhaunne, Raja-Rani, Murchungi, Adheri and Sagma forest stands, respectively (Figure 4).

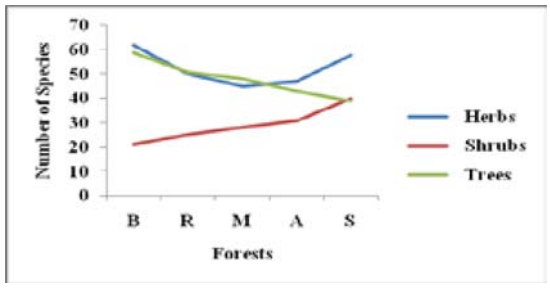

Figure 4: Trend of growth forms according to elevation of the studied forests of Morang district, east Nepal.

The maximum numbers of tree and herbs species were in Bhaunne, and highest species of shrubs were in Sagma forest (Table 1). Similarly, number of species was 127, 108, 109, 111 and 123 in B, R, M, A and S respectively (Table 1). Temperature, rainfall, humidity, soil characteristics, and other variables all have an impact on an area's vegetation, which in turn is influenced by elevation[27]. Maximum number of herbs i.e. (87%) among 266 species (201 genera, 71 families were found the study on vegetation structure and species diversity of Wadi Turbah Zahran, Albaha area, southwestern Saudi Arabia[28]. Forest composition varied continuously with elevation. Species richness is inversely proportional to the elevation gradient. In other word, species richness decreases with the increase of elevations[11,29,30,31,32,33]. Forest of low elevation are heterogeneous (more diverse) and spatially more patchy[29].

This study found only 51 species unique to Bhaunne forest; likewise 24, 13, 17 and 44 species unique to Raja-Rani, Murchungi, Adheri and Sagma forests correspondingly. There were 21 species common among all five forests (Figure 5). There were 13 species common to S and R forests, 6 species present in both B and S forests, another 6 species were common among S, R and M forests. Further, 6 species belonged to M and B forests. Likewise, the number species common to S and A forest were 12. Seven species were found common to R and A forests. Seven species were dwelled among three forests: B, M and R. Five species were common to A and B forests. Five species were common in A and M forests.

Four species were common to B, M and A forests, additionally four species were common among three forests: A, M and R. On the other hand, 12 species were encountered common to S, A and M forests, only one species was common in S and B and another one species was common among the three forests B, A and R. the number of species belonged to four forests namely: S, R, A and M were 13. Eight species were found both in S and M forests, another eight species were common in R and B forests. Extra six species were resided in M as well as B forests. Further, 13 species were common to four forests S, R, A and M. Two species only were common for A and R forests and 14 species were present among A, M, and R forests (Table 3, Figure 5).

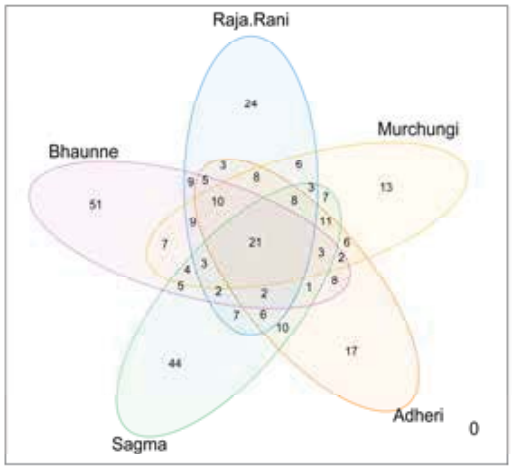

Figure 5: Venn-diagram showing community composition variation among forest types.

Species diversity and species evenness were also found decreased from low to high elevation[34,35].

The present study investigated Shannon Wiener index (H') ranged between 2.22 to 3.12 for trees, 2.21 to 2.98 for shrub, and 3.58 to 3.79 for herb among these investigated forest stands. The value of concentration of dominance (Cd) depends on the species richness and its lower values are associated with high species richness[36]. Index of dominance or concentration of dominance (cd) value ranged between 0.03 to 0.92 in herb layers, 0.08 to 0.19 in shrub layers and 0.08 to o.46 in tree layers (Table 2).

The species evenness or equitability value in this study were found ranged between 0.09 to 1.93, 0.72 to 0.8, and 0.59 to 0.88 for herbs, shrubs, and trees respectively. Margalef diversity index or species richness were ranged between 14.81 to 19.3 for herbs, 2.09 to 3.86 for shrubs, and 5.94 to 8.48 for tree layer (Table 2). Density showed positive relationship with species richness and Shannon Wiener diversity index[11,31].

The tree stand density was maximum i.e, 985 individuals ha^{-1} in Adheri forest and minimum in Sagma (602.5 individual ha^{-1}) forest. The tree density and tree basal area were found decreased with increase of elevation in a study done in Manang[31], which is contrast to present study. The highest herbs density was observed in Sagma (44.1 individuals ha^{-1}), whereas the lowest density was observed in Raja-Rani (18 individual ha^{-1}). These differences may be differences in climatic conditions.

Similarly, shrub stand density was highest in Sagma (24400 individual/ha) and lowest in Adheri forest (11320 individual ha^{-1}) among the forests (Table 1). According to study done by Kuma and Shibru, [37] in Ethiopia, Malik and Bhatt [38] in Badri Kedarnath region of India found elevation, aspects and slopes caused differences in the density and basal area, dominance and frequency of the plant species. There was also a study done in the south east facing slopes of Parroha community forest in Rupandehi District by Acharya and Shrestha[16]. They found higher species evenness, Simpson's index of dominance for all life forms in the south east slope. Alfa diversity for shrub layer was higher in the south east slope whereas beta diversity for tree layer was higher in south west slope[16].

Shorea robusta and *Schima wallichii* association was found increasing in forests of higher elevation to Adheri as their association increases with elevation. These findings also supported by study done by Sharma et al. in the western Himalayas[1]. Most of study showed unimodal trend of life form with elevation such as Bhattarai and Vetaas[11,] Gairola [32] etc. that is dissimilar of present study.

Family composition of species

The total number of family was 82 recorded by this study (Table 1). Among them Asteraceae had the maximum number of species (31 species, 28 genera) followed by Fabaceae (27 species, 21 genera) and Lamiaceae (24 species, 17 genera); Poaceae (19 species, 15 genera); Acanthaceae (13 species, 9 genera) and Rubiaceae (13

species, 12 genera) and so on. Studies such as Rawat[39] done in East Himalaya, Tegene and Gamo[40] done in Ethiopia found Myrsinaceae and Rubiaceae were the dominant families with the highest number of species. Based on individuals' density, Asteraceae contributed 744 in this study area followed by Lamiaceae, 638 individuals and Dipterocarpaceae, 544 individuals (Table 3). The numbers of families were 54 in B, 55 in R, 50 in M and S, and 52 in A (Table1). According to Dangol 2005[41], among the angiosperms, Fabaceae was the largest families in a study done in western Chitwan, which supports our present findings.

Basal area and Importance value index

The basal area of shrubs in the study area found ranging from 36.57 m^2 ha^{-1} (Bhaunne) to 111.52 m^2 ha^{-1} (Sagma) and the basal area of trees ranging from 343.53 m^2 ha^{-1} (Sagma) to 612.08 m^2 $ha^{-1,}$ (Murchungi) (Table 1). The important value index of herbs varied from 1.54 (*Ageratum conyzoides*) to 25.02 (*Oplismenus compositus*), 1.94 (*Colocasia esculenta*) to 20.07 (*Koenigia mollis*), 1.94 (*Digitaria ciliaris*) to 18.64 (*Imperata cylindrica*), 1.83 (*Globba clarkei*) to 27.52 (*Elsholtzia blanda*) and 1 (*Curculigo orchioides*) to 19.25 (*Imperata cylindrica*) in B, R, M, A and S respectively.

The importance value index of shrubs found in this study ranged from 1.47 (*Cyathula prostrata*) to 56.43 (*Clerodrendrum infortunatum*), 1.58 (*Uncaria sessilifructus*) to 60.81 (*Maesa chisia*), 2.28 (*Clerodendrum serratum*) to 30.22 (*Maesa chisia*), 1.39 (*Ototropis conferta*) to 68.74 (*Maesa macrophylla*) and 0.83 (*Flacourtia jangomas*) to 57.26 (*Maesa macrophylla*) in B, R, M, A and S forest respectively (Table 3). Likewise, the important value index value of trees was found to be ranged from 0.82 (*Cornus oblonga*) to 65.93 (*Senegalia catechu*), 0.97 (*Cornus oblonga*) to 81.81 (*Shorea robusta)* are similar to a study done by Pardi[42], 1.15 (*Dillenia pentagyna*) to 62.28 (*Terminalia alata*) and 1.05 (*Oroxylum indicum*) to 134.78 (*Shorea robusta*) similar in a study done by Napit in Banke[43] and 1.18 (*Albizia procera*) to 69.08 (*Schima wallichii*) in B, R, M, A and S forests of this study respectively (Table 3). Similar to the result of the present study, Varghese and Balasubramanyan[44] found their forests were also mainly dominated by *Shorea robusta* and *Terminalia alata* as upper canopy and the extent of dominance of tree species was different considerably in the Tarai forest *Shorea robusta* and *Shorea-Terminalia* forest at the south-western part of the Bardia National Park, Nepal. Differences in vegetation composition, and basal area may be because of disturbance as found by Giri et al.[35], the local extinction and immigration of species that is found in tropical forest as done by Bhatt and Khanal[45]. The lower values of basal area may be the result of anthropogenic disruptions as many authors agreed such as [35,45,46,47,48,49], since the forests are closer to human settlement that may lower values of basal area may be the result of anthropogenic disruptions which matches the result with Feroz, Mamun, and Kabir [46]. Human-caused disturbances such as logging, unrestricted grazing, lopping for firewood and fodder, and litter clearance have a significant negative impact on the forest as Chandra, Malik, Pandey and Bhatt [48,49]. Pardi et al.[42] found *Shorea* forest was the dominant tree species at the lower elevation. This result was different from present study.

Community composition variation after analysis of similarity (ANOSIM) showed that community structure was significantly different among 5 different forests. An ANOSIM result showed the value of R = 0.805 and p = 0.001. This indicated statistical significant difference in community composition among five forests (Figure 6).

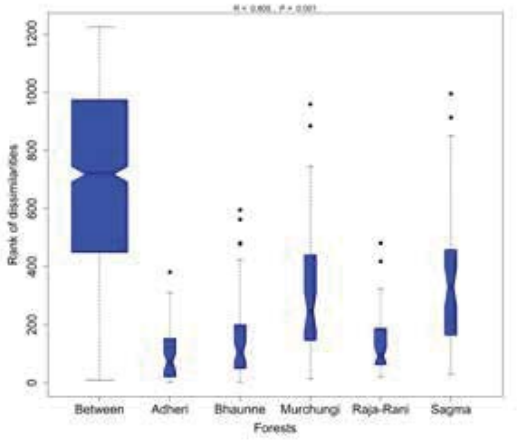

Figure: 6. Change in community composition with forest type in the study area.

According to Jha[15], diversification among different communities might be due to different environment factors such human disturbances, extensive grazing, invasive species and soil erosion resulting in fragmentation of vegetation types which in turn make impact on the community structure. This view has also been supported by similar studies such as Malik and Bhatt[51] , Shahid[52] and Joshi etc.

Table 1: Total values of phytosociological attribute of forests located at different elevation in Morang district, eastern Nepal.

Parameters	Forest stands				
	Bhaunne	**Rajarani**	**Murchungi**	**Adheri**	**Sagma**
Number of species					
Herbs	62	50	45	47	58
Shrubs	21	25	28	31	40
Trees	59	51	48	43	39
Total Species	142	126	121	121	137
Density					
Herbs (ind.m^{-2})	23.6	18	19.5	20.5	44.1
Shrubs (ind. ha^{-1})	14000	11720	14240	11320	24400
Trees (ind.ha^{-1})	935	950	775	985	602.5
Number of families	54	55	50	52	50
Number of genera	127	108	109	111	123
Basal area of shrubs (m^2 ha^{-1})	36.57	57.86	55.05	60.60	111.52
Basal area of Trees (m^2 ha^{-1})	543.09	439.82	612.08	501.04	343.53

Table 2: Diversity indices of forests located at different elevation in Morang district, eastern Nepal

Components					
Species richness (*d*)	**Bhaunne**	**Raja-Rani**	**Murchungi**	**Adheri**	**Sagma**
Herbs	19.3	16.95	14.81	15.23	15.05
Shrubs	2.09	2.56	2.82	3.21	3.86
Trees	8.48	7.28	7.06	6.11	5.94
Equitability/ Simpson's evenness (*e*)					
Herbs	0.92	1.84	1.87	0.93	0.92
Shrubs	0.72	0.78	0.85	0.84	0.8
Trees	0.76	0.72	0.72	0.59	0.88
Index of dominance (*cd*)					
Herbs	0.92	0.06	0.03	0.04	0.03
Shrubs	0.19	0.13	0.08	0.08	0.1
Trees	0.12	0.11	0.16	0.46	0.08
Shannon-Wiener index (*H'*)					
Herbs	3.79	3.67	3.65	3.58	3.78
Shrubs	2.2	2.45	2.91	2.9	2.98
Trees	3.08	2.85	2.77	2.22	3.12

Table 3: List of plant species with their importance value index (IVI) in five different forests of Morang District, Eastern Nepal.

S.N.	Site/Forests	Scientific name	Habit	Family	Occurrence	B	R	M	A	S
1	B	*Abutilon indicum* (L.) Sweet	H	Malvaceae	1	2.23	-	-	-	-
2	B,R,M,A,S	*Acer oblongum* Wall. ex DC.	T	Sapindaceae	13	4.68	2.29	2.84	5.11	5.00
3	B,R,M,A,S	*Achyranthes aspera* L.	H	Amaranthaceae	12	7.52	5.09	7.07	9.11	4.15
4	R,A,S	*Achyranthes bidentata* Blume	H	Amaranthaceae	8	-	5.09	-	4.43	6.41
5	M,A,S	*Actinodaphne lanceolata* Daizell & A. Gibson.	T	Lauraceae	8	-	-	3.85	3.21	2.36
6	R,S	*Adenostemma lavenia* (L.) Kuntze	H	Asteraceae	7	-	5.36		2.78	-
7	B,R,M,A	*Adina cordifolia* (Roxb.) Brandis	T	Rubiaceae	22	12.47	6.97	12.27	5.02	
8	B	*Aegle marmelos* (L.) Correa	T	Rutaceae	5	2.00	-	-	-	-
9	B,R,M,A,S	*Ageratina adenophora* (Spreng.) R. M. King & H. Rob.	S	Asteraceae	44	19.16	18.93	29.04	29.26	36.43
10	B,R,M,A,S	*Ageratum conyzoides* L.	H	Asteraceae	14	1.54	8.52	9.81	9.43	8.61
11	A	*Ageratum houstonianum* Miller	H	Asteraceae	2	-	-	-	4.52	-
12	B,R,M	*Alangium salviifolium* (L.f.) Wangerin	T	Cornaceae	21	15.50	7.32	6.11	-	-
13	B,R	*Albizia lebbeck* (L.) Benth.	T	Fabaceae	3	0.88	2.11	-	-	-
14	B, R, A, S	*Albizia julibrissin* Durazz.	T	Fabaceae	6	1.79	0.99		1.18	2.45
15	S	*Albizia lucidor* (Steud.) I. Neielsen ex H. Hara	T	Fabaceae	2	-	-	-	-	2.34
16	B,M,A,S	*Albizia procera* (Roxb.) benith.	T	Fabaceae	7	1.75	-	1.45	3.96	1.18
17	R,M,S	*Alnus nepalensis* D. Don	T	Betulaceae	12	-	2.22	3.06	-	12.72
18	R,S	*Alocasia fornicata* (Kunth) Schott	H	Araceae	2	-	4.32	-	-	1.49
19	B,R,A	*Alstonia scholaris* (L.) R. Br.	T	Apocynaceae	12	5.97	4.41	-	2.52	-
20	B,R,M	*Alysicarpus vaginalis* (L.) DC.	H	Fabaceae	10	2.34	4.32	7.64	-	-
21	M	*Cocculus laurifolius* DC.	H	Menispermaceae	3	-	-	10.39	-	-
22	S	*Anisomeles indica (*L.) Kuntze	H	Lamiaceae	2	-	-	-	-	3.28
23	R	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	T	Phyllanthaceae	3	-	3.25	-	-	-
24	B,R,S	*Ardisia solanacea* Roxb.	S	Myrsinaceae	16	34.04	4.75	-	-	5.07
25	A	*Ipomoea atropurpurea* (Wall.) Choisy	H	Convolvulaceae	2	-	-	-	3.61	-

26	M	*Arisaema erubescens* (Wall.) Schott	H	Araceae	2	-	-	5.10	-	-
27	M,A,S	*Artemisia indica* Willd.	S	Asteraceae	10	-	-	3.69	4.44	8.27
28	B	*Arthraxon lancifolius* (Trin.) Hochst.	H	Poaceae	2	9.34	-	-	-	-
29	M,A	*Arundinella nepalensis* Trin.	H	Poaceae	2	-	-	6.26	6.27	-
30	R,S	*Axonopus compressus* (Sw.) P. Beauv.	H	Poaceae	6	-	13.00	-	-	6.26
31		*Barleria strigosa* Willd.	S	Acanthaceae	1	2.70	-	-	-	-
32	R,A,S	*Barleria cristata* L.	H	Acanthaceae	8	-	7.07	-	7.80	2.70
33	B	*Bauhinia malabarica* Roxb.	T	Fabaceae	2	1.71	-	-	-	-
34	A	*Begonia picta* Sm.	H	Begoniaceae	2	-	-	-	4.78	-
35	S	*Berberis napaulensis* (DC.) Spring.	S	Berberidaceae	2	-	-	-	-	2.46
36	B,R,M	*Bergera koenigii* L.	S	Rutaceae	9	22.03	8.15	12.44	-	-
37	M	*Bidens pilosa* L.	H	Asteraceae	3	-	-	6.62	-	-
38	B	*Biophytum sensitivum* (L.) DC.	H	Oxalidaceae	3	6.06	-	-	-	-
39	B	*Blainvillea acmella* (L.) Philipson	H	Asteraceae	2	4.16	-	-	-	-
40	M	*Blumea balsamifera* (L.) DC.	H	Asteraceae	3	-	-	8.27	-	-
41	S	*Blumea eriantha* DC.	H	Asteraceae	2	-	-	-	-	2.51
42	B,M,A,S	*Blumea lacera* (Burm.f.) DC	H	Asteraceae	7	5.10	-	5.56	3.06	2.65
43	M,S	*Boehmeria ternifolia* D.Don	S	Urticaceae	5	-	-	3.40	-	2.93
44	S	*Boenninghausenia albiflora* (Hook) Rchb. ex Meisn.	S	Rutaceae	2	-	-	-	-	2.05
45	B	*Boerhavia diffusa* L.	H	Nyctaginaceae	2	4.18	-	-	-	-
46	B,S	*Bombax ceiba* L.	T	Malvaceae	4	4.01	-	-	-	1.67
47	R	*Breynia retusa* (Dennst.) Alston	S	Phyllanthaceae	1	-	2.27	-	-	-
48	B,M,S	*Bridelia retusa* (L.) A. Juss.	T	Euphorbiaceae	8	2.05		3.80		3.99
49	S	*Brucea javanica* (L.) Merr.	T	Simaroubaceae	3	-	-	-	-	3.59
50	S	*Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Sweet	S	Solanaceae	2	-	-	-	-	2.35
51	M,A,S	*Butea buteiformis* (Voigt) Grierson	S	Fabaceae	15	-	-	7.40	11.74	9.04
52	S	*Cajanus Scarabaeoides* (L.) Thouars	H	Fabaceae	1	-	-	-	-	1.92
53	R,M,A,S	*Callicarpa arborea* Roxb.	T	Lamiaceae	11		7.54	1.26	2.13	2.42

54	B	*Callicarpa macrophylla* Vahl	S	Lamiaceae	2	9.81	-	-	-	-
55	M,A	*Campylotropis macrostyla* (D. Don) Lindl. ex Miq.	H	Fabaceae	3	-	-	5.04	2.56	-
56	M,S	*Carex elongata* L.	H	Cyperaceae	6	-	-	9.24	-	4.26
57	R,M	*Carex hirta* L.	H	Cyperaceae	5	-	4.27	3.42	-	-
58	R	*Carex nubigena* D. Don	H	Cyperaceae	4	-	5.68	-	-	-
59	B,R,M	*Careya arborea* Roxb.	T	Lecythidaceae	7	1.72	2.04	5.05	-	-
60	R	*Caryota urens* L.	T	Arecaceae	2	-	1.99	-	-	-
61	B,R,M,A	*Casearia graveolens* Dalzell	T	Salicaceae	24	6.98	3.17	1.28	8.97	-
62	B,R	*Cassia fistula* L.	T	Fabaceae	9	4.42	5.13	-	-	-
63	R,M,A,S	*Castanopsis indica* (Roxb. ex Lindl.) A. DC.	T	Fagaceae	19	-	6.23	4.47	3.21	24.23
64	A,S	*Castanopsis tribuloides* (Sm.) A. DC.	T	Fagaceae	8	-	-	-	3.82	4.36
65	R	*Catunaregam spinosa* (Thunb.) Tirveng.	S	Rubiaceae	2	-	6.26	-	-	-
66	A	*Celastrus paniculatus* Wild.	S	Celastraceae	2	-	-	-	3.07	-
67	S	*Celastrus stylosus* Wall.	S	Celastraceae	2	-	-	-	-	1.75
68	B,R,M,S	*Centella asiatica* (L.) Urb.	H	Apiaceae	9	5.95	6.18	7.62	-	4.47
69	M,A,S	*Chonemorpha fragrans* (Moon) Alston.	S	Apocynaceae	11	-	-	5.64	3.27	6.80
70	B,R,M,A,S	*Chromolaena odorata* (L.) R. M. King & H. Rob.	S	Asteraceae	40	13.28	13.88	19.37	25.07	23.96
71	B	*Chrysopogon aciculatus* (Retz.) Trin.	H	Poaceae	2	4.97	-	-	-	-
72	M,A	*Chrysopogon zizanioides* (L.) Roberty	H	Poaceae	4	-	-	8.76	4.61	-
73	S	*Cinnamomum tamala* (Buch-Ham.) T. Nees & C.H.Eberm.	T	Lauraceae	5	-	-	-	-	4.12
74	R,A,S	*Cipadessa baccifera* (Roxb. Ex Roth) Miq.	S	Meliaceae	8	-	6.88	-	4.88	1.94
75	M,S	*Clematis buchananiana* DC.	H	Ranunculaceae	3	-	-	3.65	-	2.56
76	S	*Clerodendrum colebrookianum* Walp.	S	Lamiaceae	5	-	-	-	-	3.74
77	B,R,M,A,S	*Clerodendrum japonicum* (Thunb.) Sweet	S	Lamiaceae	16	7.33	5.45	4.35	4.52	3.06
78	M,A	*Clerodendrum serratum* Spreng.	S	Lamiaceae	3	-	-	2.28	2.21	-
79	B,R,M,A,S	*Clerodrendrum infortunatum* L.	S	Lamiaceae	32	56.43	33.38	20.91	13.70	4.80

80	B,R,M,A,S	*Colebrookea oppositifolia* Sm.	S	Lamiaceae	31	11.81	11.31	28.45	18.55	9.08
81	R,M	*Colocasia esculenta* (L.) Schott	H	Araceae	5	-	1.94	5.37	-	-
82	S	*Colquhounia coccinea* Wall.	S	Lamiaceae	5	-	-	-	-	6.19
83	R,M	*Combretum roxburghii* Spreng.	S	Combretaceae	4	-	10.71	19.92	-	-
84	B,R,M,A	*Commelina benghalensis* L.	H	Commelinaceae	10	5.22	5.38	8.01	8.80	-
85	S	*Commelina caroliniana* Walter	H	Commelinaceae	2	-	-	-	-	2.37
86	R	*Commelina suffruticosa* Blume	H	Commelinaceae	6	-	10.53	-	-	-
87	B,R,M	*Cornus oblonga* Wall.	T	Cornaceae	4	0.82	0.97	3.08	-	-
88	B,A	*Cosmos bipinnatus* Cav.	H	Asteraceae	4	2.60	-	-	4.66	-
89	A,S	*Crassocephalum crepidioides* (Benth.) S. Moore	H	Asteraceae	2	-	-	-	2.62	1.44
90	B,R	*Croton persimilis* Mull. Arg.	T	Euphorbiaceae	21	8.93	25.74	-	-	-
91	B,R,M,A,S	*Curculigo orchioides* Gaertn.	H	Hypoxidaceae	7	1.54	2.89	4.17	5.74	1.00
92	R	*Curcuma angustifolia* Roxb.	H	Zingiberaceae	3		5.58	-	-	-
93	A	*Cyanotis cristata* (L.) D. Don	H	Commelinaceae	2	-	-	-	4.38	-
94	B,A	*Cyanthillium cinereum* (L.) H. Rob.	H	Asteraceae	3	2.67	-	-	4.33	-
95	B	*Cyathula prostrata* (L.) Blume	S	Amaranthaceae	1	1.47	-	-	-	-
96	B,R,M,A,S	*Cynodon dactylon* (L.) Pers.	H	Poaceae	11	10.18	2.08	12.12	10.90	15.55
97	B,R,A,S	*Cyperus brevifolia* Rottb. Hassk	H	Cyperaceae	10	4.12	14.37	-	8.27	3.85
98	R	*Cyperus difformis* L.	H	Cyperaceae	7	-	13.92	-	-	-
99	R,M	*Cyperus exaltatus* Retz.	H	Cyperaceae	6	-	3.33	5.18	-	-
100	B	*Cyperus rotundus* L.	H	Cyperaceae	1	2.28	-	-	-	-
101	B,R,M,A	*Dalbergia latifolia* Roxb.	T	Fabaceae	10	1.74	3.08	5.23	4.51	
102	B	*Dalbergia sissoo* Roxb.	T	Fabaceae	2	1.95	-	-	-	-
103	R,M,A	*Dalbergia stipulacea* Roxb.	T	Fabaceae	15	-	9.59	14.35	4.63	-
104	R	*Debregeasia longifolia* (Burm. f.) Wedd.	S	Urticaceae	2	-	3.78	-	-	-
105	R	*Desmos chinensis* Lour.	S	Annonaceae	2	-	3.22	-	-	-
106	S	*Dicliptera bupleuroides* Nees.	H	Acanthaceae	2	-	-	-	-	5.16
107	M	*Dicliptera chinensis* (L.) Juss.	H	Acanthaceae	2	-	-	6.52	-	-

108	B	*Dictyospermum montanum* Wight	H	Commelinaceae	2	3.73	-	-	-	-
109	B,R,M,A,S	*Digitaria ciliaris* (Retz.) Koeler	H	Poaceae	11	5.95	15.44	1.94	6.20	3.33
110	B	*Digitaria setigera* Roth	H	Poaceae	1	2.62	-	-	-	-
111	B,R,M,A	*Dillenia pentagyna* Roxb.	T	Dilleniaceae	9	5.50	1.78	1.15	3.41	
112	S	*Dimetia scandens* (Roxb.) R.J.Wang	H	Rubiaceae	2	-	-	-	-	3.57
113	B,R,A	*Diospyros chloroxylon* Roxb.	T	Ebenaceae	11	2.64	3.03	-	2.16	-
114	M	*Diospyros montana* Roxb.	T	Ebenaceae	2	-	-	1.53	-	-
115	B,M,A	*Diploknema butyracea* (Roxb.) H. J. Lam	T	Sapotaceae	15	6.76	-	2.82	5.99	-
116	R	*Docynia indica* (Colebr.ex Wall.) Decne.	T	Rosaceae	1	-	1.03	-	-	-
117	B,R,M,A,S	*Drymaria diandra* Blume	H	Caryophyllaceae	8	1.54	4.42	5.70	6.00	5.15
118	R,M,S	*Duabanga grandiflora* (Roxb. ex DC.) Walp	T	Lythraceae	6	-	1.01	2.66	-	4.53
119	M,A,S	*Duhaldea cappa* (Buch.-Ham. ex D. Don) Pruski & Anderb.	S	Asteraceae	12	-	-	7.10	6.33	5.24
120	B	*Eclipta prostrata* (L.) L.	H	Asteraceae	1	2.28	-	-	-	-
121	B,R,A	*Ehretia acuminata* (DC.) R. Br.	T	Boraginaceae	20	9.09	4.76	-	2.10	-
122	B,R,M,A,S	*Elaeagnus infundibularis* Momiy.	S	Elaeagnaceae	11	9.91	8.15	9.92	4.08	11.47
123	A	*Elaeodendron glaucum* (Rottb.) Pers.	T	Celastraceae	2	-	-	-	2.14	-
124	S	*Elatostema platyphyllum* Wedd.	H	Urticaceae	1	-	-	-	-	1.36
125	B,M	*Eleusine indica* (L.) Gaertn.	H	Poaceae	2	1.76	-	2.11	-	-
126	A,S	*Elsholtzia blanda* (Benth.) Benth.	H	Lamiaceae	16	-	-	-	27.52	14.14
127		*Emilia sonchifolia* (L.) DC.	H	Asteraceae	2	3.73	-	-	-	-
128	M,A,S	*Engelhardia spicata* Lechen ex Blume	T	Juglandaceae	17	-	-	4.80	7.41	44.25
129	B,M	*Eragrostis tenella* (L.) P. Beauv.ex Roem. & Schult.	H	Poaceae	3	5.52	-	6.69	-	-
130	R	*Erigeron canadensis* L.	H	Asteraceae	3	-	5.26	-	-	-
131	S	*Erythrina stricta* Roxb. ·	T	Fabaceae	2	-	-	-	-	4.62
132	R,M,A	*Eschenbachia leucantha* (D. Don) Brouillet	H	Asteraceae	6	-	4.14	4.63	3.06	-
133	B,R,S	*Euphorbia hirta* L.	H	Euphorbiaceae	5	2.02	2.00	-	-	4.91

134	S	*Eurya acuminata* DC.	T	Pentaphylacaceae	3	-	-	-	-	5.39
135	B,R	*Evolvulus nummularius* (L.) L.	H	Convolvulaceae	5	4.24	6.17	-	-	-
136	B,M,A,S	*Falconeria insignis* Royle	T	Euphorbiaceae	21	5.51	-	5.29	3.19	11.29
137	M	*Ficus hispida* L. f.	S	Moraceae	3	-	-	8.57	-	-
138	B	*Ficus lacor* Buch.-Ham.	T	Moraceae	1	1.06	-	-	-	-
139	S	*Ficus neriifolia* Sm.	T	Moraceae	4	-	-	-	-	6.10
140	B	*Ficus racemosa* L.	T	Moraceae	2	2.03	-	-	-	-
141	B,M,S	*Ficus semicordata* Buch.-Ham. ex Sm.	T	Moraceae	7	1.68	-	3.32	-	3.53
142	S	*Flacourtia jangomas* (Lour.) Raeusch.	S	Salicaceae	1	-	-	-	-	0.83
143	M,A	*Flemingia paniculata* Wall. ex Benth.	S	Fabaceae	4	-	-	2.76	2.84	-
144	B	*Flemingia strobilifera* (L.) W. T. Aiton	S	Fabaceae	2	4.27	-	-	-	-
145	R	*Floscopa scandens* Lour.	H	Commelinaceae	5	-	3.42	-	-	-
146	B,R,M	*Garuga pinnata* Roxb.	T	Burseraceae	10	2.30	2.19	3.81	-	-
147	S	*Girardinia diversifolia* (Link) Friis	S	Urticaceae	3	-	-	-	-	3.33
148	R,M,A	*Globba clarkei* Baker	H	Zingiberaceae	5	-	3.02	2.79	1.83	-
149	B	*Globba racemosa* Sm.	H	Zingiberaceae	2	5.10	-	-	-	-
150	B,M	*Gmelina arborea* Roxb. ex Sm.	T	Lamiaceae	5	2.91	-	2.67	-	-
151	B	*Gnaphalium polycaulon* Pers.	H	Asteraceae	1	1.74	-	-	-	-
152	M,A,S	*Gonostegia hirta* (Blume) Miq.	H	Urticaceae	6	-	-	3.62	7.02	4.21
153	B,M,S	*Grewia optiva* J. R. Drumm. ex Burret	T	Malvaceae	5	1.76	-	1.50	-	2.48
154	B,S	*Grona triflora* (L.) H. Ohashi & K. Ohashi	H	Fabaceae	5	8.10	-	-	-	3.80
155	S	*Gynocardia odorata* R. Br.	T	Achariaceae	3	-	-	-	-	5.86
156	B	*Hedychium ellipticum* Buch.-Ham. ex Sm.	H	Zingiberaceae	3	6.29	-	-	-	-
157	R,M	*Hedychium flavescens* Carey ex Roscoe	H	Zingiberaceae	3	-	4.25	2.08	-	-
158	B	*Hedyotis diffusa* Willd.	H	Rubiaceae	2	3.88	-	-	-	-
159	B	*Hemarthria compressa* (L. f.) R. Br.	H	Poaceae	2	5.42	-	-	-	-
160	B,R,M	*Heynea trijuga* Roxb. ex Sims	T	Meliaceae	5	1.97	4.63	2.70	-	-

161	B,R	*Holarrhena pubescens* Wall. ex G. Don.	T	Apocynaceae	5	2.52	1.94	-	-	-
162	B	*Holoptelea integrifolia* (Roxb.) Planch.	T	Ulmaceae	1	4.19	-	-	-	-
163	R,S	*Homalium napaulense* (DC) Benth.	T	Salicaceae	3	-	3.27	-	-	1.19
164	R	*Hydrocotyle sibthorpioides* L.	H	Araliaceae	2	-	4.10	-	-	-
165	B	*Hygrophila auriculata* (Schumach.) Heine	H	Acanthaceae	2	3.99	-	-	-	-
166	B,R,M,A,S	*Imperata cylindrica* (L.) Raeusch.	H	Poaceae	16	2.67	3.28	18.64	25.67	19.25
167	S	*Indigofera* sp.	S	Fabaceae	1	-	-	-	-	1.07
168	S	*Isodon coetsa* (Buch.-Ham. ex D. Don) Kudô	H	Lamiaceae	2	-	-	-	-	5.11
169	A	*Isodon* sp.	S	Lamiaceae	2	-	-	-	2.70	-
170	B	*Jasminum amabile* H. Hara	S	Oleaceae	2	3.44	-	-	-	-
171	B,R,M,A,S	*Justicia adhatoda* L.	S	Acanthaceae	15	8.43	5.34	6.05	2.38	6.58
172	R	*Knema tenuinervia* W. J. de Wilde	T	Myristicaceae	2	-	1.03	-	-	-
173	R,A,S	*Koenigia mollis* (D. Don) T. M.Schust. & Reveal	H	Polygonaceae	11	-	20.07	-	5.65	4.17
174	B,R,A	*Lagerstroemia parviflora* Roxb.	T	Lythraceae	23	9.65	7.31	-	3.90	-
175	R,M	*Laggera alata* S. Moore	S	Asteraceae	6		3.29	5.24	-	-
176	B,A	*Lannea coromandelica* (Houtt.) Merr.	T	Anacardiaceae	6	1.32	-	-	2.40	-
177	B,R,M,A,S	*Lantana camara* L.	S	Verbenaceae	22	8.22	10.52	9.54	9.32	7.34
178	B,S	*Leea indica* (Burm. f.) Merr.	S	Vitaceae	12	34.24	-	-	-	5.18
179	R,M,A	*Leea macrophylla* Roxb. ex Hornem.	S	Vitaceae	16	-	54.45	24.10	4.46	-
180	S	*Leucas decemdentata* (Willd.) Sm.	H	Lamiaceae	2	-	-	-	-	5.02
181	R,M,A	*Leucomeris spectabilis* D. Don	S	Asteraceae	6	-	3.59	3.94	3.27	
182	S	*Leucosceptrum canum* Sm.	T	Lamiaceae	2	-	-	-	-	2.76
183	A	*Ligustrum robustum* (Roxb.) Blume	T	Oleaceae	2	-	-	-	2.10	-
184	A	*Lindenbergia grandiflora* Benth.	H	Orobanchaceae	1	-	-	-	3.06	-
185	R,M,A,S	*Litsea monopetala* (Roxb.) Pers.	T	Lauraceae	14	-	3.38	5.22	3.69	8.67
186	B	*Litsea salicifolia* (Roxb. ex Nees) Hook. f.	S	Lauraceae	6	22.19	-	-	-	-
187	R,M,A,S	*Macaranga indica* Wight	T	Euphorbiaceae	12	-	3.72	3.55	3.20	3.53

188	B,R,M,A,S	*Maesa chisia* D. Don.	S	Primulaceae	41	25.83	60.81	30.22	24.37	18.95
189	R,M,A,S	*Maesa macrophylla* (Wall.) A. DC.	S	Primulaceae	33	-	3.86	20.14	68.74	57.26
190	B,R	*Mallotus nudiflorus* (L.) Kulju & Welzen	T	Euphorbiaceae	8	6.55	3.08	-	-	-
191	B,R,M,A,S	*Mallotus philippensis* (Lam.) Müll. Arg.	T	Euphorbiaceae	17	5.95	3.61	1.53	3.24	5.59
192	M	*Martynia annua* L.	S	Martyniaceae	2	-	-	3.17	-	-
193	B,A,S	*Melastoma malabathricum* L.	S	Melastomataceae	10	1.90	-	-	5.41	7.29
194	S	*Mentha canadensis* L.	H	Lamiaceae	3	-	-	-	-	7.05
195	M,S	*Micromelum integerrimum* (Roxb. ex DC.) Wight & Arn. ex Voigt	T	Rutaceae	4	-	-	2.70	-	4.00
196	B,R,M,A,S	*Mikania micrantha* Kunth	H	Asteraceae	11	3.40	7.98	3.02	8.16	4.40
197	B,M	*Miliusa velutina* (DC) Hook. f. & Thomson	T	Annonaceae	4	2.05	-	1.53	-	-
198	M,A	*Millettia extensa* (Benth.) Benth. ex Baker	S	Fabaceae	4	-	-	2.82	3.21	-
199	B,S	*Mimosa pudica* L.	H	Fabaceae	6	4.73	-	-	-	5.17
200	M	*Murdannia nudiflora* (L.) Brenan	H	Commelinaceae	2	-	-	5.54	-	-
201	R	*Mussaenda macrophylla* Wall.	S	Rubiaceae	4	-	12.35	-	-	-
202	B	*Neolamarckia cadamba* (Roxb.) Bosser	T	Rubiaceae	2	1.91	-	-	-	-
203	R,M,A	*Neolitsea cuipala* (D. Don) Kosterm.	T	Lauraceae	8	-	2.62	1.21	4.93	-
204	S	*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & S. H. Oh	T	Fagaceae	3	-	-	-	-	4.33
205	A	*Nyctanthes arbor-tristis* L.	S	Oleaceae	3	-	-	-	7.73	-
206	B,R,M,A,S	*Oplismenus compositus* (L.) P. Beauv.	H	Poaceae	20	25.02	6.49	8.53	18.35	15.90
207	B,R,M	*Oplismenus hirtellus* (L.) P. Beauv.	H	Poaceae	5	2.82	10.62	4.48	-	-
208	B,A	*Oroxylum indicum* (L.) Kurz	T	Bignoniaceae	5	1.73	-	-	1.05	-
209	R	*Orthosiphon incurvus* Benth.	H	Lamiaceae	2	-	10.25	-	-	-
210	M,S	*Osbeckia stellata* Buch.-Ham. ex D. Don	S	Melastomataceae	6	-	-	3.22	-	4.56
211	S	*Ostodes paniculata* Blume	T	Euphorbiaceae	5	-	-	-	-	7.72
212	B, A	*Ototropis conferta* (DC.) H. Ohashi & K. Ohashi	S	Fabaceae	2	1.90	-	-	1.39	-

213	B	*Ougeinia oojeninensis* (Roxb.) Hochr.	T	Fabaceae	4	2.44	-	-	-	-
214	B,R	*Oxalis corniculata* L.	H	Oxalidaceae	4	6.60	3.28	-	-	-
215	R	*Oxalis latifolia* Kunth.	H	Oxalidaceae	1	-	3.14	-	-	-
216	B,A	*Paederia* foetida L.	H	Rubiaceae	4	3.27	-	-	4.60	-
217	R	*Paramignya monophylla* Wight	S	Rutaceae	4	-	2.07	-	-	-
218	A,S	*Paspalum conjugatum* P.J. Bergius	H	Poaceae	6	-	-	-	10.01	12.55
219	M	*Paspalum notatum* Flüggé	H	Poaceae	3	-	-	11.01	-	-
220	A	*Peperomia pellucida* (L.) Kunth	H	Piperaceae	1	-	-	-	3.32	-
221	S	*Persicaria capitata* (Buch.-Ham. ex D. Don) H. Gross	H	Polygonaceae	2	-	-	-	-	2.57
222	S	*Persicaria pubescens* (Blume) H. Hara	H	Polygonaceae	2	-	-	-	-	2.41
223	B,R,M,A	*Phanera vahlii* (Wight & Arn.) Benth.	T	Fabaceae	13	3.62	4.46	4.22	3.79	-
224	A	*Phragmites karka* (Retz.) Trin. ex Steud.	H	Poaceae	1	-	-	-	2.95	-
225	B	*Phyllanthus amarus* Schumach. & Thonn.	H	Phyllanthaceae	2	4.08	-	-	-	-
226	S	*Phyllanthus clarkei* Hook. f.	S	Phyllanthaceae	3	-	-	-	-	3.19
227	B,R,M,A	*Phyllanthus emblica* L.	T	Phyllanthaceae	8	1.68	2.07	1.49	3.69	-
228	B	*Phyllanthus virgatus* G. Forst.	H	Phyllanthaceae	2	4.75	-	-	-	-
229	S	*Pilea symmeria* Wedd.	H	Urticaceae	1	-	-	-	-	1.34
230	B,M	*Piper longum* L.	H	Piperaceae	4	5.46	-	2.28	-	-
231	S	*Platostoma hispidum* (L.) A. J. Paton	H	Lamiaceae	2	-	-	-	-	5.02
232	B,M	*Pleurolobus gangeticus* (L.) J. St.-Hil.ex H. Ohashi & Ohashi	H	Fabaceae	4	3.40	-	5.93	-	-
233	R,S	*Pogonatherum crinitum* (Thunb.) Kunth	H	Poaceae	2	-	2.95	-	-	2.38
234	R,S	*Pogostemon amaranthoides* Benth.	H	Lamiaceae	4	-	3.14	-	-	6.48
235	B,R,M,S	*Pogostemon benghalensis* (Burm. f.) Kuntze	H	Lamiaceae	21	24.01	11.64	12.51		10.22
236	A	*Pouzolzia rugulosa* (Wedd.) Acharya & Kravtsova	T	Urticaceae	2	-	-	-	1.35	-
237	B	*Pouzolzia zeylanica* (L.) Benn.	H	Urticaceae	2	3.70	-	-	-	-
238	B	*Prasoxylon excelsum* (Spreng.) Mabb.	T	Meliaceae	3	1.16	-	-	-	-

239	B	*Premna mollissima* Roth	T	Verbenaceae	12	0.93	-	-	-	-
240	A,S	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P. D. Cantino	S	Lamiaceae	6	-	-	-	5.22	8.52
241	S	*Pseudognaphalium adnatum* (Dc.) Y. S. Chen	H	Asteraceae	1	-	-	-	-	1.92
242	R	*Pseudognaphalium affine* (D. Don) Anderb.	H	Asteraceae	2	-	4.12	-	-	-
243	B	*Pseudognaphalium luteoalbum* (L.) Hilliard & B. L. Burtt	H	Asteraceae	3	6.86	-	-	-	-
244	R	*Pterospermum acerifolium* (L.) Willd.	T	Malvaceae	1	-	1.17	-	-	-
245	S	*Firmiana colorata* (Roxb.) R. Br.	T	Malvaceae	2	-	-	-	-	2.95
246	B	*Rauvolfia serpentina* (L.) Benth. ex Kurz.	S	Apocynaceae	1	1.61	-	-	-	-
247	S	*Reinwardtia indica* Dumort.	S	Linaceae	2	-	-	-	-	1.73
248	A	*Rhynchoglossum obliquum* Blume	H	Gesneriaceae	1	-	-	-	2.95	-
249	B,M,S	*Rostellularia obtusa* Nees	H	Acanthaceae	11	5.99	-	11.64	-	8.68
250	M	*Rotheca serrata* (L.) Steane & Mabb.	S	Lamiaceae	2	-	-	2.70	-	-
251	S	*Rubia manjith* Roxb.	H	Rubiaceae	1	-	-	-	-	1.49
252	A,S	*Rubus ellipticus* Sm.	S	Rosaceae	8	-	-	-	5.20	5.55
253	R,A,S	*Rungia himalayensis* C.B. Clarke	H	Acanthaceae	6	-	3.37	-	4.89	5.09
254	B,M,A	*Rungia pectinata* (L.) Nees	H	Acanthaceae	6	1.84	-	11.29	4.48	-
255	S	*Sambucus javanica* subsp. *Chinensis* (Lindl.) Fukuoka	S	Adoxaceae	1	-	-	-	-	1.47
256	S	*Sarcococca coriacea* (Hook.) Sweet	S	Buxaceae	3	-	-	-	-	4.80
257	A,S	*Saurauia napaulensis* DC.	T	Actinidiaceae	4	-	-	-	2.51	2.47
258	R,M,A,S	*Schima wallichii* (DC.) Korth.	T	Theaceae	40	-	48.22	16.29	19.81	69.08
259	B,M	*Schleichera oleosa* (Lour.) Oken	T	Sapindaceae	3	2.61	-	2.43	-	-
260	B	*Scoparia dulcis* L.	H	Plantaginaceae	1	3.19	-	-	-	-
261	B,A	*Scutellaria repens* Buch.-Ham. ex D.Don	H	Lamiaceae	3	10.04	-	-	1.83	-
262	S	*Scutellaria scandens* D. Don	H	Lamiaceae	3	-	-	-	-	4.08
263	B,R,M,A	*Semecarpus anacardium* L.f.	T	Anacardiaceae	16	6.24	4.27	15.71	5.17	-
264	B	*Senegalia catechu* (L.f.) P. J. H. Hurter & Mabb.	T	Fabaceae	1	65.93	-	-	-	-

265	M	*Senegalia intsia* (L.) Maslin, Seigler & Ebinger	T	Fabaceae	2	-	-	3.71	-	-
266	B,R,M,A	*Shorea robusta* C.F. Gaertn.	T	Dipterocarpaceae	40	37.04	81.81	47.08	134.78	-
267	M,A,S	*Sida acuta* Burm f.	H	Malvaceae	8	-	-	7.07	7.28	4.91
268	A	*Sida cordata* (Burm. f.) Borss. Waalk.	H	Malvaceae	1	-	-	-	2.62	-
269	S	*Sida rhombifolia* L.	H	Malvaceae	3	-	-	-	-	4.24
270	R	*Smilax aspera* L.	H	Smilacaceae	3		7.12	-	-	-
271	B	*Solanum nigrum* L.	H	Solanaceae	1	2.34	-	-	-	-
272	R,S	*Solanum viarum* Dunal	S	Solanaceae	2	-	5.02	-	-	1.02
273	R,A	*Solanum virginianum* L.	H	Solanaceae	5	-	6.17	-	4.43	-
274	B	*Sonchus asper* (L.) Hill	H	Asteraceae	1	2.81	-	-	-	-
275	S	*Spermacoce alata* Aubl.	H	Rubiaceae	3	-	-	-	-	7.63
276	B,A	*Spermacoce ocymoides* Burm.f.	H	Rubiaceae	2	1.74	-	-	3.06	-
277	A,S	*Spermadictyon suaveolens* Roxb.	S	Rubiaceae	5	-	-	-	4.67	1.60
278	B	*Spondias pinnata* (L. f.) Kurz	T	Anacardiaceae	1	1.10	-	-	-	-
279	B,R,A	*Sterculia villosa* Roxb.ex Sm.	T	Malvaceae	7	0.97	1.39	-	1.89	-
280	B	*Streblus asper* Lour.	T	Moraceae	2	1.67	-	-	-	-
281	R,M,A,S	*Strobilanthes capitata* (Nees) T. Anderson	H	Acanthaceae	9	-	2.07	5.81	8.72	8.16
282	R,M,S	*Strobilanthes glutinosa* Nees.	H	Acanthaceae	6	-	2.95	5.33		4.70
283	B	*Strobilanthes hirta* (Vahl) Blume	H	Acanthaceae	1	2.02	-	-	-	-
284	B	*Synedrella nodiflora* (L.) Gaertn.	H	Asteraceae	4	8.30	-	-	-	-
285	A	*Synotis cappa* (Buch.-Ham. ex D. Don) C. Jeffrey & Y. L. Chen	H	Asteraceae	1	-	-	-	2.88	-
286	B,R,M,A,S	*Syzygium cumini* (L.) Skeels	T	Myrtaceae	20	3.78	2.30	5.31	7.01	7.64
287	B,R	*Syzygium nervosum* A. Cunn. ex DC.	T	Myrtaceae	2	0.86	1.08	-	-	-
288	B	*Tamarindus indica* L.	T	Fabaceae	2	2.16	-	-	-	-
289	B,R,M	*Terminalia bellirica* (Gaertn.) Roxb.	T	Combretaceae	3	0.86	1.08	3.64	-	-
290	B,R,M,S	*Terminalia chebula* Retz.	T	Combretaceae	7	1.86	1.05	3.35	-	3.04
291	M	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	T	Combretaceae	3	-	-	6.02	-	-

292	B,R,M,A	*Terminalia alata* Dietr.	T	Combretaceae	6	2.22	1.29	62.28	4.24	-
293	M,A,S	*Tetradium fraxinifolium* (Hook.) T.G. Hartley	T	Rutaceae	10	-	-	3.01	4.15	7.38
294	R	*Tetrameles nudiflora* R. Br.	T	Tetramelaceae	1	-	1.40	-	-	-
295	A,S	*Tetrastigma serrulatum* (Roxb.) Planch.	H	Vitaceae	5	-	-	-	7.74	2.58
296	A	*Thalictrum punduanum* Wall.	S	Ranunculaceae	3	-	-	-	4.27	-
297	R,A	*Thunbergia alata* Bojer ex Sims.	H	Acanthaceae	2	-	2.00	-	3.06	-
298	S	*Thyrsanthella* sp.	H	Apocynaceae	2	-	-	-	-	2.99
299	M,A,S	*Thysanolaena latifolia* (Roxb. ex Hoenem.) Honda	S	Poaceae	7	-	-	3.61	5.04	3.06
300	R,M,A	*Toona ciliata* M. Roem.	T	Meliaceae	3	-	1.02	1.29	2.05	
301	R	*Torenia crustacea* (L.) Cham. & Schltdl.	H	Linderniaceae	2	-	5.25	-	-	-
302	R,M,A,S	*Toxicodendron succedaneum* (L.) Kuntze	T	Anacardiaceae	9	-	1.00	2.34	4.61	4.23
303	B	*Trema orientalis* (L.) Blume.	T	Cannabaceae	2	1.68	-	-	-	-
304	B	*Tridax procumbens* L.	H	Asteraceae	1	1.57	-	-	-	-
305	M,S	*Triumfetta pilosa* Roth	H	Malvaceae	5	-	-	3.16	-	5.44
306	R,S	*Uncaria sessilifructus* Roxb.	S	Rubiaceae	4	-	1.58	-	-	2.95
307	B,S	*Urena lobata* L.	H	Malvaceae	5	1.84	-	-	-	5.50
308	M,S	*Urtica dioica* L.	H	Urticaceae	5	-	-	8.41	-	2.43
309	B	*Veronica javanica* Blume	H	Plantaginaceae	1	4.35	-	-	-	-
310	R,M,A	*Wendlandia heynei* (Schult.) Santapau & Merchant	T	Rubiaceae	6	-	1.97	1.20	1.33	-
311	A,S	*Woodfordia fruticosa* (L.) Kurz	S	Lythraceae	10	-	-	-	8.64	7.08
312	M,A,S	*Wrightia arborea* (Dennst.) Mabberly	T	Apocynaceae	8	-	-	4.57	3.39	2.94
313	B,R	*Youngia japonica* (L.) DC.	H	Asteraceae	2	3.32	2.95	-	-	-
314	R,A,S	*Zanthoxylum armatum* DC.	T	Rutaceae	6	-	0.97	-	1.05	4.01
315	B	*Zizyphus jujuba* Mill.	T	Rhamnaceae	3	2.75	-	-	-	-

B = Bhaunne; R = Raja-Rana; M = Murchungi; A = Adheri; S = Sagma

Conclusions

Understanding the distribution of species along the forests at different elevation, it is essential for the conservation of biodiversity and prioritizing areas for conservation planning. The present study was carried out to assess the variation in community structure, composition and diversity of plant species along different forests. It supported the 'U shaped' species richness pattern wherein higher number of species are 142 reported at lower elevation i.e, at Bhaunne forest. The results indicated that Sagma is the most favorable region for growth of shrub species and least favorable for tree species. Herb also showed U shaped pattern among the forests, while tree species was in decreasing order and shrub species was in increasing pattern along the forest at high elevations. Thus, we can say that more diverse plant communities exist at studied forests. The present study assists the policymakers in developing the sound strategies for conservation and sustainable management of ecosystem. The stakeholders such as Ministry of Forests, Departments, University, Province level ministry, Forest Division and local community forest user group, and other related organizations might plan approaches for regeneration and sustainable forest management together with conservation actions of plant species.

The present study revealed that Bhaunne forest is having the highest species richness for herbs and tree species, Shannon's diversity and commonness of species. The number of species across forests (alpha diversity) did not vary greatly, but species composition among forests differed appreciably resulting into a fair compositional heterogeneity (beta diversity). The presence of Asteraceae with 31 species, 28 genera was remarkable. A pattern of mixed dominance of trees 65.93 (*Senegalia catechu*), 81.81 (*Shorea robusta),* 62.28 (*Terminalia alata*), 134.78 (*Shorea robusta*) and 69.08 (*Schima wallichii*) in B, R, M, A and S forest respectively was noteworthy.

The density of herbs and shrubs was maximum in Sagma forests and density of tree was high in Adheri forests. The value of basal area of shrubs and trees was considerably high in Sagma and Murchungi forests.

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Soil organic carbon stocks in the forests of different continents

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Abstract
Carbon stocks in soil vary substantially across the globe depending on the type of forests, their locations, and soil depths. We applied meta-analysis to 64 relevant published data with no restriction of published date, country, and journals. However, it was always kept in mind to include high impacted journals. The aim of this review was to evaluate whether soil organic carbon (SOC) varies with forest types, soil depths, and altitudes. Globally, the SOC stocks in the forests were found in the order of Boreal forest (BF) > Subalpine forest (SAF) > Temperate forest (TeF) > Afromontane forest (AfMF) > Montane forest (MF) > Subtropical forest (SF) > Alpine forest (AF) > Tropical forest (TF) ranging from 64.3 t/ha to 206.6 t/ha, the minimum is in tropical forest and maximum in the boreal forest. The SOC stocks were also found varied with soil depths and forests of different continents too. The maximum value of SOC stocks was 366.94 t/ha in 0-40 cm soil depth and the minimum value was 20.16 t/ha in the 80-100 cm soil depth. Linear relationship of SOC stocks was obtained with altitudes, the value increases along the increasing elevations. In conclusion, SOC stocks varied as forests, soil depths, and elevations.

Keywords: Elevation, forest types, soil depth, soil organic carbon, SOC stocks

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Introduction

Soil is the largest sink of organic carbon on the earth. It has the ability to stock 1.5-3 times more amount of carbon than the plants in the forest ecosystem (Lal, 2004; Stockmann *et al*., 2013; Ciais *et al.,* 2014). It is a key component in the global carbon cycle and an important indicator of sustainable forestry (Davidson and Janssens, 2006; Bangroo *et al.,* 2017). Minor changes in the stock of soil organic carbon (SOC) in terrestrial ecosystems may affect the global carbon cycle (Lal, 2005; Nave *et al.,* 2010; Li *et al.,* 2013).

Soil organic carbon is influenced by climate (Davidson and Janssens, 2006), soil physical properties, disturbance regimes such as fire (Harden *et al.,* 2015), deforestation (Tolessa and Senbeta, 2018), and landslides (Błońska *et al.,* 2018). Climate affects both plant growth and yields, and it mediates decomposition rates thus impacting the quantity and rate of carbon cycling. Nevertheless, there are several other controlling factors such as topography (Cardinael *et al.*, 2017), soil type (Albaladejo *et al.,* 2013; Zhang *et al.*, 2020), soil depth (Li *et al.*, 2013; Niu *et al*., 2015; Lozano-García *et al.,* 2016; Pandey and Bhusal, 2016), soil biota (Zhang *et al.*, 2020), forest types (Tewksbury and Van Miegroet, 2007; Baishya and Barik, 2011), altitudes (Bangroo *et al.,* 2017) and aspects (Lozano-García *et al.*, 2016). However, altitude is not directly influencing the ecosystem but it influences climatic factors mainly temperature and moisture to a great extent (Dar and Somaiah, 2015) that

governs the nature of the vegetation and process of soil formation (Chaudhari *et al.,* 2013). SOC increases with precipitation and clay content gradients and decreases with temperature gradient (Jobbágy and Jackson, 2000; Bhattacharyya *et al.*, 2008), which has been confirmed on regional and global scales (Yang and Feng, 2007). Temperate forests show increasing trend in SOC stocks with increasing altitude (Zhu *et al*., 2010). Sometimes surface soil is not strongly related with altitude (Dieleman *et al.*, 2013).

Rainfall increases with altitude, which characterizes the soil properties, soil processes and its formation (Dahlgran *et al.,* 1997) hence influences biomass production. Soil moisture increases with altitude up to temperate climate and decline thereafter reaching the lowest in upper alpine. Soil temperature will be highest in tropical and subtropical conditions; which declines with the altitude. These probably make soil moisture and soil temperature suitable for the optimum growth, productivity and litter production in temperate forests thereby resulting highest SOC stock build up in the temperate climate (Zhu *et al.,* 2010; Singh *et al.,* 2011; Dar and Sundarapandian, 2016). Intensive sunlight radiation at less dominated by large trees with closed canopy in lower altitude may also facilitate organic matter formation on the soil (Liu *et al.*, 2018). Human and animal interference is also high in lower altitude which may lead to an accumulation of manure and other organic substance which in return might also be resulted in accelerated decomposition of litters. Thus amount of SOC storage depends upon rate of decomposition and carbon input, vegetation types and its net primary productivity, soil properties (Tian *et al.*, 2010). Species variability, type, age, soil and climatic variability, aboveground biomass and belowground biomass, dead wood, litter, herbaceous biomass and soil also affect the change in SOC stocks (Yosef *et al.*, 2019).

Top soil layer found to have lower bulk density that means soil is better for the plant growth as compared to soil at the lower depth (Ali *et al*., 2017; Ghimire *et al.*, 2018). That means SOC contents is less with the increasing soil depth but bulk density is high. Lower layer of soil contains less fine roots, less SOC stocks, less soil contents, soil dwelling organisms and high compaction (Bajracharya *et al.*, 2004; Shrestha and Singh, 2008). The soil organic carbon (SOC) stocks decreases with increasing soil depths (Sheikh *et al.*, 2009; Sakin *et al*., 2011; Chaudhari *et al.*, 2013), while Bulk density (BD) increasing with increase in the depth of soil profile for all the land uses as the soil property remains less. Degraded soil contains low SOC stocks due to lower amount of organic matter (Chaudhari *et al.*, 2013), which happened due to lowering input of leaf litter, low decomposition of fine roots, greater soil disturbances, lower root biomass and loss of vegetation (Rattan Lal, 2014; Ghimire *et al*., 2018). The review tried to document the average value of SOC stocks in different forests and even SOC stocks by forest types in different continents. It gives an idea that which continent is rich in forest diversity and rich in SOC stocks even in soil properties.

Materials and Methods

Reviewing of literatures focusing on SOC and altitudes, forest types and soil depths was done through online database and search engines. Google scholar, ResearchGate, Nepjol, Agora, Hinari were used to search literature. During search keywords such as “carbon stock”, “soil”, “soil organic carbon”, “forest soil”, “forest”, “forest carbon”, “SOC altitudinal gradient”, “and soil depth” were used in order to include maximum relevant literatures. We crosschecked references of relevant articles centered on SOC. We critically reviewed each searched literature. The steps of literature reviewed are given in the Figure 1. There was no limitation of countries and year of publications. We found a total of 37 journals with impact factor ranging from 0.07 to 4.8 and 8 journals were without impact factors but listed under ISI.

A matrix based on information about forest types, altitude, soil depth and SOC from each literature was prepared. The measurement unit of SOC stocks was made uniform i.e all were converted into ton per hectare (t/ha) unit. The unit of altitudes in feet from the sea level was converted into meter and the unit of soil depth for all literature was made uniform by changing into centimeter (cm), if they were in meter (m) or other

units. The aim of this review is to review the patterns of SOC stocks along varied altitudes along different forest types and the soil depths. Data matrixes were used to analyze response and predictors. Soil organic carbon was the main response and the response variable was analyzed against forest types, countries, soil depth. Each analyzed result was presented in the form of figure. F-statistics was used in order to compare significant P-value among categorical forest types, depths. Data were analyzed with the help of R software (R Core Team, 2020).

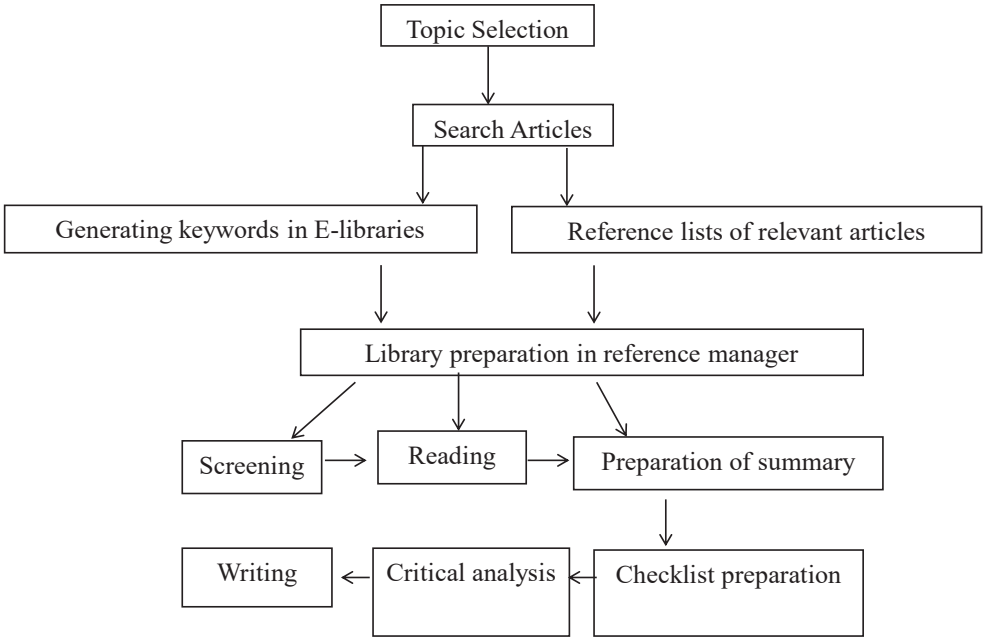

Figure 1. Flow chart of conceptual framework.

Results and Discussion

Soil organic carbon in different forest types

Soil organic carbon varied significantly in various forests types. Averaging the value of all similar forests of different continents the values of SOC stocks were ranging from 64.3 t/ha to 206.6 t/ha from tropical forests to boreal forests (Figure 2). The values of SOC stocks in different forests recorded showed the pattern of increasing trend in the order of BF > SAF > TeF > AfMF > MF > SF > AF > TF. The highest value of SOC stocks was recorded in the boreal forests and the lowest in tropical forests. Soil organic carbon is known to be a very dynamic entity which varies across forest types. Fascinatingly, different forest types showed different pattern of soil organic carbon stocks, which may be dense to the inclusion of all available data across the globe (various forest plots differing in age, disturbance, regime, climate, species composition, and edaphic conditions etc). Inconsistent to the present result, boreal forests were found to concern high SOC stocks than the temperate forest which may be due to tree species composition (Asase *et al*., 2012; Chand *et al*., 2018), edaphic factors (McFarlane *et al*., 2013), sampling density (Yuan *et al.*, 2013), aspects (Sharma *et al.*, 2011). Tropical forest on the other hand were found to have the lowest SOC stocks which might be due to deforestation *(Gurung et al.,* 2015) as also suggested by Chand *et al.*

(2018). Terai tropical forests (Pandey and Bhusal, 2016; Bhattarai and Mandal, 2018) regenerating forest (Behera and Sahani, 2003), opposite of this the SOC stocks were high in afforested forests with improved soil quality (Nwaogu *et al.*, 2018) and managed forests (Kafle, 2019). The highest SOC stock in boreal forest of Asia perhaps because of lowest decomposition rate and low efflux of CO_2 from the soil (Tewksbury and Van Miegroet, 2007). While in montane forest of this continent showed lowest SOC stock might be due to effect of high altitude, where litter input is low resulting low carbon accumulation in the soil (Shaheen *et al.*, 2017). SOC stock in the boreal forest of Asia was greater than in the temperate forest (Wei *et al.*, 2013; Zhu *et al.*, 2017). Temperate forests of Africa showed the highest value of SOC stocks than other continents.

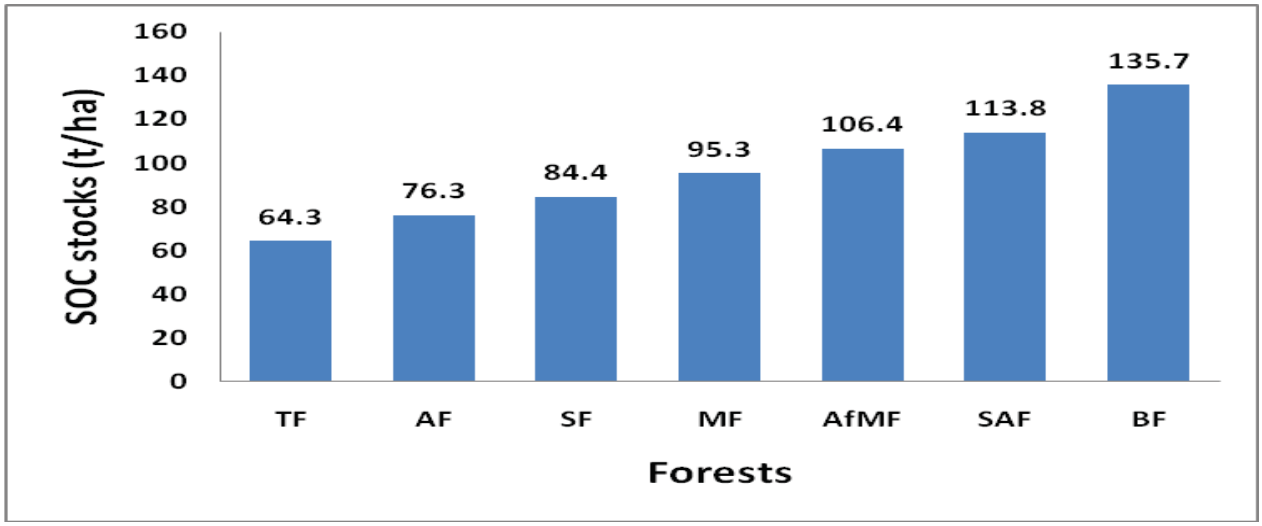

Figure 2. Forest types and their mean SOC stocks.

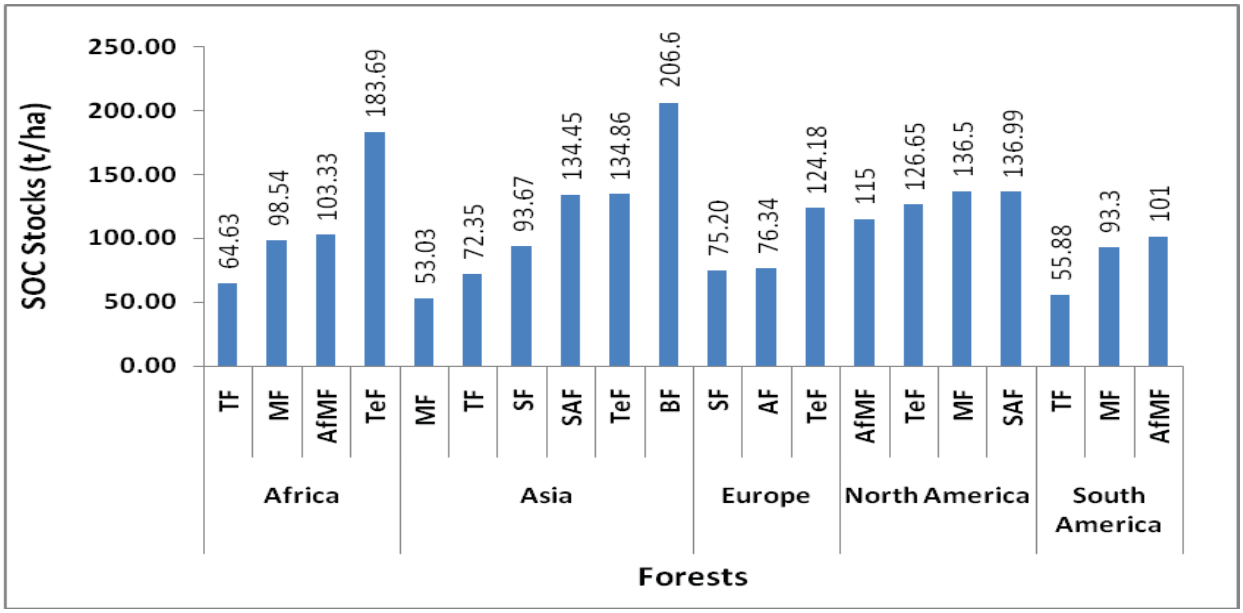

Figure 3. SOC Stocks by forest types in different continents.

The result showed low value of SOC stocks in tropical forest in different continents. SOC depends upon the quantity of litter in the floor and biomass (Tashi *et al.*, 2016). While tropical forests of India contained larger canopy tree like *Pinus smithiana* and *Abies pindrowand* forests

(Gupta and Sharma, 2011; Bohra *et al.*, 2015) and higher SOC stocks in lower altitudes that might be due to increase in tree species diversity, changes in species composition and soil microbial and micro fungal biomass (Behera and Sahani, 2003). The estimates of SOC stocks of temperate forests significantly higher in Africa, Temperate forests have experienced low human and natural disturbances and relatively low temperature and moderately high precipitation, which slow down the decomposition process (Zhu *et al*., 2010).

The climatic conditions in the temperate forests are suitable for growth, productivity and litter production. Suitable temperature and moisture possibly favour production of larger fine particles in soil along with high amount of litter that forms the organo-mineral complexes, ultimatly producing highest SOC stocks in the temperate forests (Singh *et al.*, 2011). Climate change and forest management systems also play role to increase of soil organic carbon, such as harvested forests revealed higher SOC stock (Suberi *et al.*, 2016). Higher accumulation of SOC stock in temperate forests might be because of forest temperature, composition, forest basal area as well as quantity of leaf litter (Tashi *et al*., 2016) Temperate forest encountered relatively high SOC stocks that might be because of soil under mixed species (Maraseni and Pandey, 2014), presence of iron, clay and less disturbance in temperate forests (Limbu *et al*., 2013).

Soil type and lithology play important role for accumulation of soil organic carbon (Albaladejo *et al*., 2013). Annual precipitation and texture are known as predictors in forest lands. In contradiction of the present review SOC stock decreases with decreasing rainfall in humid climatic conditions where there is less vegetation cover (Sinoga *et al.*, 2012). Soil organic carbon (SOC) stocks generally increases with forest age, cool temperature combined with high precipitation. The soil organic carbon (SOC) stocks distribution pattern is closely similar in the Afro-Montane forests of America and Africa which may be due to similar environmental conditions (temperature and precipitation conditions) and rate of decomposition (Eshetu and Hailu, 2020; Dahlgren *et al*., 1997; Twongyirwe *et al.*, 2013). Alpine forests showed moderately lower SOC stocks among the other forests that may be due to climatic condition and land use change (Martín *et al.*, 2016). And they also reported as topsoil had higher SOC stocks, indicates higher biomass production in the north Spain in the alpine region.

SOC stocks along soil depths

Mostly, soil carbon is available in the form of organic carbon obtained from the living organisms stored in deep soil layers (below 20 cm) over long period of time (Fontaine *et al.*, 2007).

In the upper 10 cm soil thickness, the highest SOC stocks i.e. 94.95 t/ha was recorded in the upper layer which gradually deceased to SOC stocks value, 37.21 t/ha in lower layer of 20-30 cm soil depth (Figure 4a) due to litter deomposition and forest types and species, resulting low organic matter in the inner layer (Wei *et al*., 2013; Albaladejo *et al.*, 2013; Ali *et al*., 2017; Adhikari and Ghimire, 2019; Pandey *et al.*, 2019). High value of SOC stocks might be due to effect of vegetations (Ranabhat *et al.*, 1997, Sinoga *et al.*, 2012; Mahato *et al.*, 2016). Interestingly, the SOC stocks at 20 cm thickness of soil, the SOC stocks value showed more or less dumbbell shaped curve, where high value were revealed in the 30-50cm of soil depth (Figure 4b). In contrast, in the 30 cm thickness of soil, the value of SOC stocks showed in dumbbell shaped curve and the lowest value of SOC stocks was in the middle in 10-40 cm soil depth (Figure 4c).

High amount of SOC stock in top layer than the lower or inner soil layer is due to high soil organic carbon matter content in the upper layer of soil and favourable conditions for rapid decomposition of forest litter (Sheikh *et al.,* 2009; Dahal and Bajracharya, 2012; Shrestha and Devkota, 2013). SOC gradually decreases in the inner soil depth due to low leaf litter and root litter contents and their decomposition (Zhang and Ding, 2017). Similarly, in the lowest depth, there is low microbial biomass which impacts input and output activities of soil (Sharma *et al*., 2014). On the other hands, the highest SOC stocks (122.38 t/ha) were revealed in the soil depth 30-50cm. In contradiction of this result, it was also recorded that the lower soil organic carbon in upper layer than the inner layer of the soil, which is surprising (Twongyirwe, *et al*., 2013; Sharma *et al.,* 2014;

Tashi *et al.*, 2016). It was also observed that low SOC stocks in the upper most layer, 0-30cm than the inner most layer, 30-60cm. In contrast top soil contains more nutrients which is responsible for higher SOC stocks (Niu *et al.*, 2015; Nwaogu *et al.*, 2018). The high SOC stocks in deeper soil (30-100cm) depth is due to fine soil particles and land use factor (Singh *et al.*, 2011), which favours the present review study. Bulk density also responsible for variation in SOC stocks; Soil depth brings variation in bulk density i.e. gradual increase in bulk density with the increase in soil depth. Top soil layer contains lower bulk density that means soil is better for the plant growth compare to the lower depth of soil. So SOC content is less with the increasing soil depth but bulk density is high (Sheikh *et al.*, 2009; Chaudhari *et al.*, 2013). Lower layer of soil contains less fine roots, less soil contents, soil dwelling organisms, high compaction and less property which consequently resulting in having less SOC stocks (Bajracharya *et al.*, 2004; Shrestha and Singh, 2008).

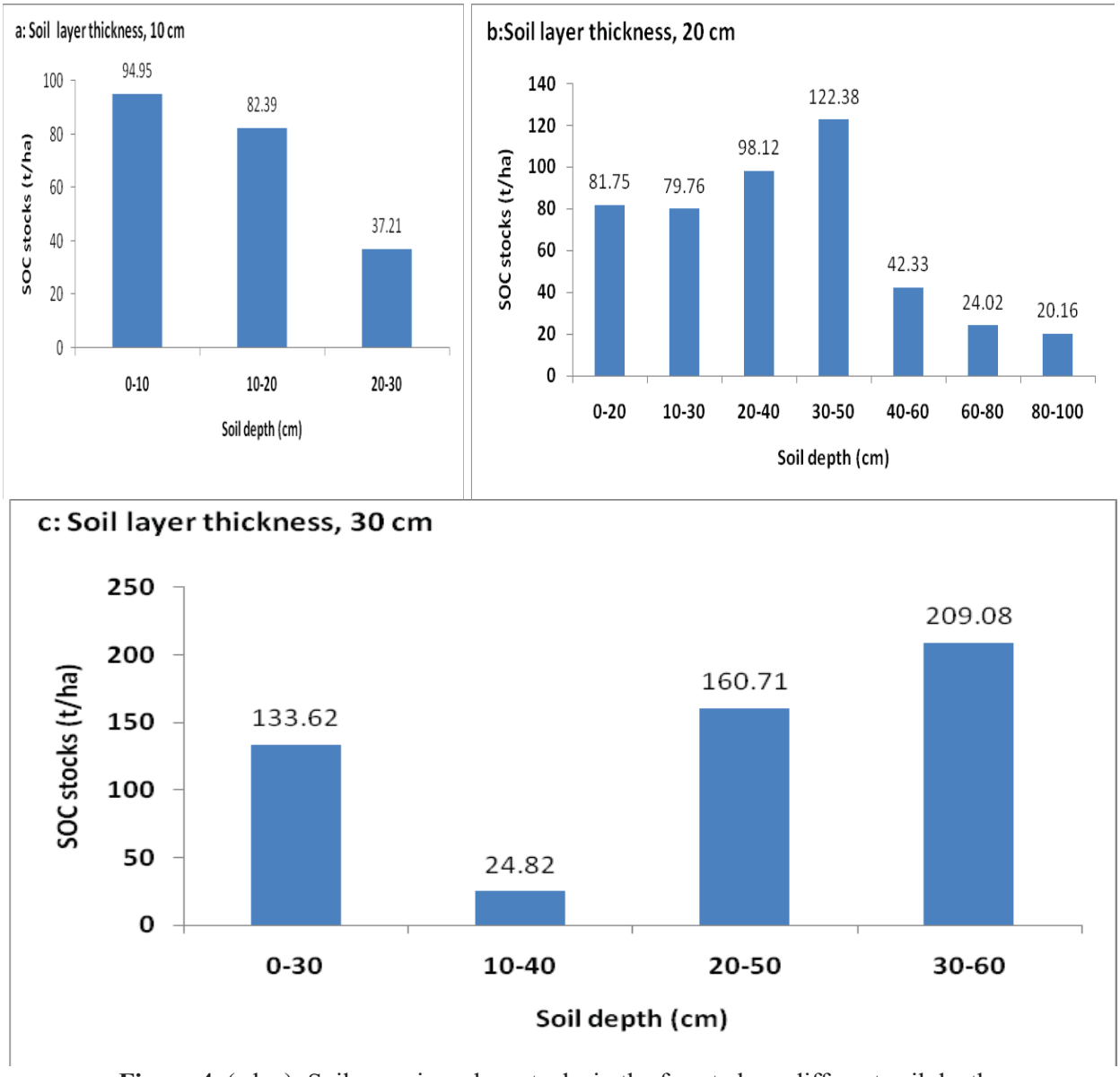

Figure 4. (a,b,c); Soil organic carbon stocks in the forest along different soil depths.

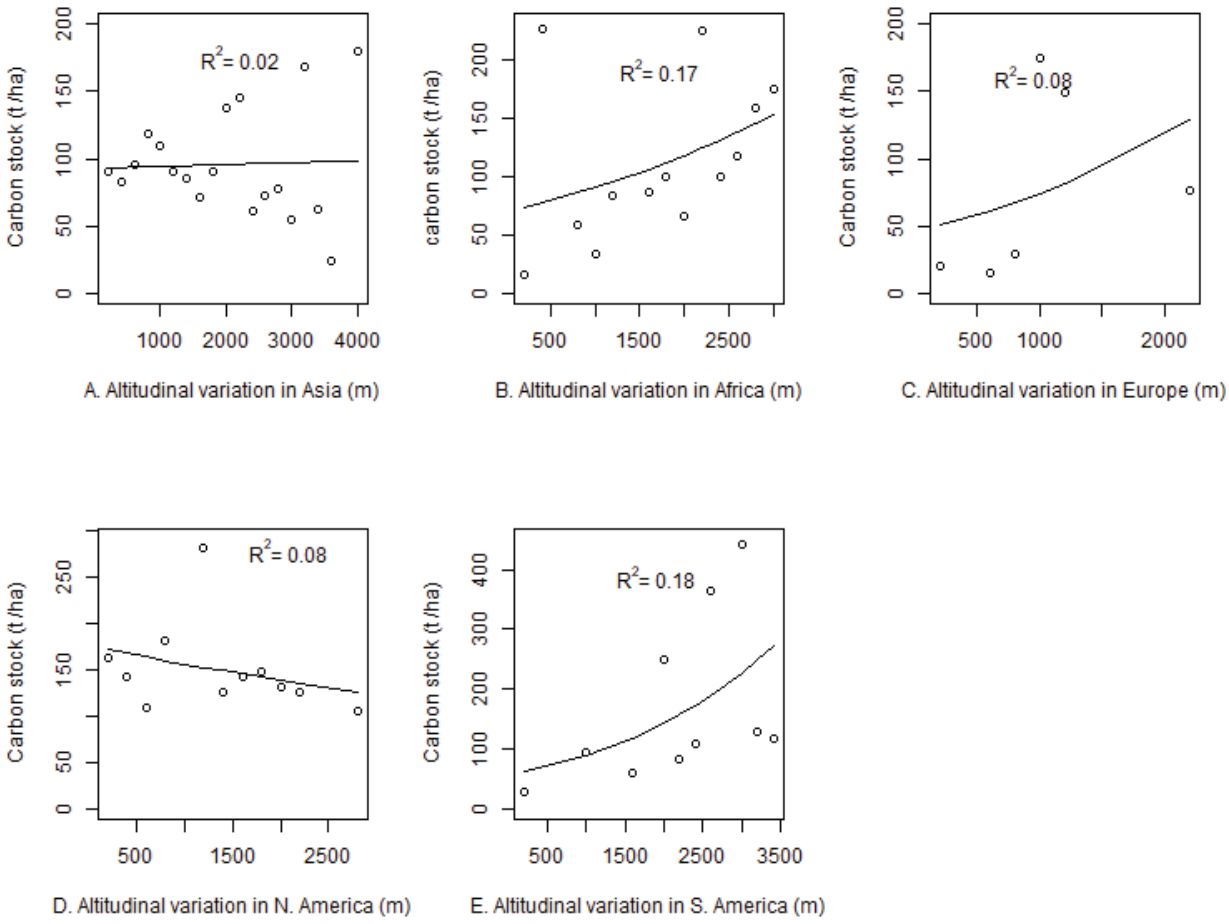

Figure 5. Forest soil organic carbon stocks along varied elevations in different continents.

Soil organic carbon along variation in altitudes

Altitudes play significant role in the variation of SOC stocks (Ji *et al*., 2015).The soil organic carbon stocks value showed linear relationship with altitude. It means the soil organic carbon stocks increases when the altitude increases in forests of all continents (Figure 5). When altitude increases, temperature decreases and precipitation becomes maximum. Temperature and moisture alter the rate of decomposition SOC stocks showed significantly an increasing trend with increase in altitude (Maraseni and Pandey, 2014; Dar and Somaiah, 2015; Tashi *et al*., 2016), climatic condition (Chen *et al.,* 2017; Salinas *et al*., 2011) , and age of tree species (Sharma *et al.,* 2009). Altitude was not a variable directly influencing the ecosystem but it influences climatic factors mainly temperature and moisture to a great extent (Dar and Somaiah, 2015). SOC stocks in temperate climate was higher than the subtropical climate (Singh *et al.*, 2011). SOC stocks in the hill sal forests was high than the tarai sal forests (Bhattarai and Mandal, 2018).

In contrast to the above statement, SOC stocks consistently exhibited decreasing pattern along increasing elevations (Sheikh *et al*., 2009b; Shaheen *et al*., 2017; Bangroo *et al*., 2017), as in higher altitude there was low vegetation which results low accumulation of litter and low input of organic carbon (Bohra *et al.*, 2015). On the other hand no clear trend of SOC stocks with altitude (Ranabhat *et al.*, 1997) which might be due to change in aspects. SOC stocks showed fluctuation

along the altitude (Jiang *et al.*, 2019). The result showed SOC stocks were positively correlated with increasing altitude in the forests of Africa, Europe and South America. High SOC stocks with increasing altitude may be due tree species, species diversity, abundance and richness of species with high liter fall. *Juniperous* species are responsible for high SOC stocks (Manaye *et al.*, 2019). While in North America, forests showed decreasing pattern of SOC stocks with increasing altitude (Leuschner and Moser, 2011; Tewksbury and Miegroet, 2007. Low SOC stocks was reported in temperate forests which might be the effect of soil depths, temperature and precipitation or climatic conditions and boosts up biomass production because of better soil aggregation (Sinoga *et al.*, 2012; Albaladejo *et al.,* 2013). SOC stocks increases with increasing altitudes (Usuga *et al.*, 2010) as total annual rainfall increase with altitude, which controls the soil properties, soil process and development (Dahlgren *et al.*, 1997).

Conclusion

The present review concluded that the total SOC stocks in Africa, Asia, Europe, N america and south America was 450.19 t/ha, 488.36 t/ha, 275.72 t/ha, 515.14 t/ha, 250.18 t/ha respectively. Among them the SOC stocks was highest in north America and lowest in south America. The SOC stocks vary with forest type and soil depths. Globally, the SOC stocks in the forests were found in the order of BF> SAF> TeF> AfMF> SF> MF> AF> TF. This indicates that wood productions is increasingly limited by environmental constraints or assimilate shortage when approaching the uppermost limit of tree growth. Generally, soil organic carbon stocks decreases with increasing soil depths. Altitude alters the soil organic carbon of forests. SOC stocks show linear relationship with altitudes. That means the soil organic carbon stock increases with increasing altitude in the forests of all continents but the relation is not so strong.

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B. Participation in Conferences with oral and poster presentation

B.1 International conference on Biodiversity, Food, Security, Sustainability and Climate Change (ICBFSCC-2023) organized by Assam Agricultural University, Jorhat, India. **Key note speaker**, Title: "Ethnobotanical study and Biodiversity of medicinal plants used in Letang Raja-Rani forests and its adjoining area, Morang, east Nepal".

B.2 9th National Conference on Science and Technology organized by Nepal Academy of Science and Technology (NAST) held on June 26-28, 2022. **Oral**, Title: "Fine root Biomass and their Nutrient Concentrations in the Forests located along elevation gradient in the Tropical region of eastern Nepal".

B.3 1st International Conference on Environmental on Climatic Change and Ecosystem Restoration organized by Environmental Science Discipline, Khulna University, Khulna, 9208, Bangladesh on February 19-20, 2022. **Oral**, Title: "Soil properties and fine root contents in moist tropical forests of eastern Nepal".

B.4 International Conference on Biodiversity and Bioprospecting organized by Department of Plant Resources, Government of Nepal, Ministry of Forest and Environment, on June 22-24, 2022. **Oral**, Title: "Soil properties in two different forests located along elevational gradients in eastern Nepal".

B.5 2021 TransTip & TPE Summer School Virtual Conference including Philosophy of Science, Global Climate Change, Mountain Sustainability Environmental Humanities

B.6 National Conference on Integrating Biological Resources for Prosperity held on February 6-7, 2020 at Biratmagar. **Poster**, Title: "Effects of Abiotic factors and disturbances on forest plant community structure".

C. Training attainted

C.1 Workshop on Research Writing and Publishing organized by Research Management Cell, Mahendra Morang Adarsha Multiple Campus, Biratnagar and supported by University Grants Commission, Nepal held at Biratnagar from May 8-11, 2019.

Platinum Jubillee Celebration of College of Agriculture, Jorhat

INTERNATIONAL CONFERENCE ON BIODIVERSITY, FOOD SECURITY, SUSTAINABILITY & CLIMATE CHANGE (ICBFSCC-2023)

Conference Secretariat ICBFSCC-2023
Assam Agricultural University, Jorhat
&
Prof. H.S. Srivastava Foundation For Science, Lucknow.

Certificate

This is to certify that

Mr./Ms./Prof. / Dr. Pramila Gachhadar, Central Dept. of Botany, Tribhuvan University, Nepal.

has delivered in the International Conference On Biodiversity, Food Security, Sustainability & Climate Change (ICBFSCC-2023) as a Lead lecture/Invited talk/Plenary lecture/Keynote speaker entitled

Ethnobotanical study & Biodiversity of medicinal plants used in the Letang RajaRani forest & its adjoining area, Morang, East Nepal.

Ranjan Das
Dr. Ranjan Das
Organizing Secretary
ICBFSCC-23

Jayanta Deka
Dr. J.Deka
Chairman
ICBFSCC-23

R.P.S.
Dr. R.P. Singh
Secretary
P.H.S.S. Foundation, Lucknow

Nepal Academy of Science and Technology (NAST)

CERTIFICATE OF PARTICIPATION

Awarded to

PRAMILA KUMARI GACHHADAR

for Presentation in Oral / ~~Poster~~ / ~~Participation~~ in the

9th National Conference on Science and Technology

June 26-28,2022 (Asar 12-14, 2079)

Khumaltar, Lalitpur, Nepal

Ms. Luna Vajra
Chief, Promotion Division

Prof. Dr. Mahesh K. Adhikari
Secretary

Dr. Sunil Babu Shrestha
Vice Chancellor

1st International Conference on Environment

Climate Change and Ecosystem Restoration

Organized by

Environmental Science Discipline

Khulna University, Khulna 9208, Bangladesh

https://discipline.ku.ac.bd/es

Certified that, Professor Dr./Mr./Ms. ***Pramila Kumari Gachhadar*** *has contributed in the 1st International Conference on Environment and participated with an* ***Oral Presentation****/ Poster presentation/as Session Chair/ as Session Co-chair/ as Rapporteur/ as Observer – that was held during February 19-20, 2022.*

Professor Dr. Mahmood Hossain
Vice Chancellor, Khulna University
Chief Patron of the Conference
Khulna 9208, Bangladesh

Dilip Kumar Datta *PhD*
Professor, Environmental Science Discipline
Convener of the Conference
Khulna University, Khulna 9208, Bangladesh

Abdullah Harun Chowdhury *PhD*
Professor and Head
Environmental Science Discipline
Organizing Secretary of the Conference
Khulna University, Khulna 9208, Bangladesh

Government of Nepal
Ministry of Forests and Environment
Department of Plant Resources
Thapathali, Kathmandu

Certificate of Participation

This certificate is awarded to

Ms. Pramila Gachhadar

*for presenting **Oral** in the*

INTERNATIONAL CONFERENCE ON BIODIVERSITY AND BIOPROSPECTING

held from 22nd to 24th June, 2022 in Kathmandu, Nepal.

Mr. Saroj Kumar Chaudhary	Dr. Buddi Sagar Poudel	Dr. Pem Narayan Kandel
Co-ordinator	Chairman	Secretary
Conference Technical Committee	Conference Organizing Committee	Ministry of Forests and Environment

Certificate of Achievement

IRTG Geo-ecosystems in Transition on the Tibetan Plateau (TransTiP)
Third Pole Environment Programme (TPE)
Institute of Tibetan Plateau Research, Chinese Academy of Science (ITP-CAS)
Kathmandu-Center for Research and Education CAS-TU (KCRE)

hereby acknowledge the successful participation of

Pramila Kumari Gachhedar

at the

2021 TransTiP & TPE Summer School

Virtual Conference from June 28 to July 9, 2021

including:

Philosophy of Science, Global Climate Change,
Mountain Sustainability, Environmental Humanities

This certificate accounts for 2 credit points.

Prof. Dr. Antje Schwalb
Speaker of **TransTiP** / Technische Universität Braunschweig

Prof. Dr. YAO Tandong
TPE co-chair / Institute of Tibetan Plateau Research CAS

Technische Universität Braunschweig · TPE Third Pole Environment · Geo-ecosystems in Transition on the Tibetan Plateau (TransTiP) · KCRE · Leibniz Universität Hannover · Friedrich-Schiller-Universität Jena · 中国科学院 Chinese Academy of Sciences · DFG

List of Lectures / Workshops

- Alpine permafrost and mechanical implications: examples from Zugspitze and other high mountain environments
- Basic facts about climate change
- Climate change impact on riverine runoff and sediment flux over the Tibetan Plateau
- Deadly Dreams and Paradise on Earth: Environmental Humanities presented through two case studies
- Lakes in Tibetan Plateau and Global Changes-Response, Trends and Coping
- Philosophy of Science: On the logic of scientific discovery
- The global carbon cycle
- The observation and modeling of air-land interaction over heterogeneous landscapes of the Third Pole
- The rhythm of the ice ages - searching for a holy grale using cosmogenic nuclides and biomarker analyses
- Tibetan pastoralists, grassland vulnerability & mountain sustainability in transdisciplinary research
- Unusual warm/humid climate boosted the Tibetan Empire prosperity in Early Medieval Period
- "Picture a scientist" – Woman in Science: film screening & panel discussion
- Assessing land-atmosphere CO2 exchange at lake Nam Co on the Tibetan Plateau using Eddy Covariance
- Remote sensing of active periglacial landforms within the western Nyainqêntanglha Range, Tibetan Plateau
- The cryosphere of the Western Nyainqêntanglha range, Tibetan Plateau

National Conference on Integrating Biological Resources for Prosperity

Certificate of Participation

This is to certify that

.....Ms. Pramila Gachhadar.....

has presented Paper / Poster / Attended the

National Conference on Integrating Biological Resources for Prosperity

held at Biratnagar on February 6-7, 2020.

Prof. Dr. Mohan Siwakoti	**Prof. Dr. Sasinath Jha**	**Dr. Bishwa Nath Oli**	**Hon. Jagadish Prasad Kusiyait**
Chairman	Chairman	Secretary	Minister
Conference Organizing Committee	Nepal Biological Society	Ministry of Forests and Environment	Ministry of Industry, Tourism, Forests and Environment
President, Botanical Society of Nepal			Province No. 1

WORKSHOP ON RESEARCH WRITING AND PUBLISHING

8th-11th May, 2019

Certificate

This is to Certify that Mr./Mrs. Pramila Gachhadar

of Central Department of Botany, TU, Kirtipur participated in the Workshop on Research Writting & Publishing organized by Research Management cell, Mahendra Morang Adarsh Multiple Campus, Biratnagar & supported by University Grants Commission, Nepal held at Biratnagar from 8th–11th May, 2019.

Prof. Dr. Devendra Adhikari
(Facilitator)

B.R. Timalsena
Mr. Baburam Timalsena
(Campus Chief)
M.M.A.M. Campus, Biratnagar

Dr. Tilak Prasad Gautam
(Co-ordinator)
Workshop Organizing Committee,
Reaserch Management Cell,
M.M.A.M. Campus, Biratnagar

FIELD PHOTOS

Curcuma angustifolia Roxb

Alangium salviifolium (L.f.) Wangerin

Clerodendrum japonicum (Thunb.) Sweet

Melastoma malabathricum L

Lantana camara L.

Maesa macrophylla (Wall.) A. DC.

Activities during the field work

प्रदेश सरकार
प्रदेश नं.१
उद्योग, पर्यटन, वन तथ वातावरण मन्त्रालय
प्रदेश वन निर्देशनालय

डिभिजन वन कार्यालय मोरङ

विराटनगर ।

फोन नः ०२१-४६०४०४

प. सं. २०७६/०७७ (प्रशासन)
च.नं. २६९

मितिः २०७६/०६/०२

विषयः *तथ्याङ्क संकलन गर्न अनुमति दिइएको सम्वन्धमा।*

श्री प्रमिला गच्छदार, P.Hd. अनुसन्धानकर्ता,
केन्द्रिय वनस्पती विभाग, त्रिभुवन विशविद्यालय ।

प्रस्तुत विषयमा केन्द्रिय वनस्पतिशास्त्र विभाग त्रिभुवन विश्वविद्यालय **(CENTRAL DEPARTMENT OF BOTANY, TRIBHUVAN UNIVERSITY)** को मिति २०७६/०५/१२ चलानी नं.१२८ भएको पत्र बमोजिम **"Species Diversity and Vegetation types of Rajarani and adjoining Forest Landscape Morang District, Eastern Nepal"** शिर्षकमा **P.Hd.**(विद्यावारीधी) गर्दै रहनु भएका तपाई श्री प्रमिला गच्छदारलाई उक्त क्षेत्रमा प्रतिकुल असर नपर्ने गरी **P.Hd.** प्रयोजनको लागी मात्र तथ्याङ्क संकलन गर्ने अनुमती दिइएको छ। तथ्याङ्क संकलनको सिलसिलामा कुनै समस्या भए यस कार्यालयसंग सम्पर्क/जानकारी/परामर्श गर्नु हुन अनुरोध छ।

साथै शोधपत्रको मस्यौदा प्रस्तुतिकरणको बखत यस कार्यालयका प्रतिनिधी समेत राख्ने व्यवस्था गर्नु हुन तथा अन्तिम शोधपत्रको एक प्रति यस कार्यालयलाई उपलब्ध गराउनु हुन अनुरोध छ।

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विशाल घिमिरे
डिभिजनल वन अधिकृत

डिभिजनल वन अधिकृत
अधिकृतस्तर दर्शा

बोधार्थः

केन्द्रिय बनस्पतीशास्त्र विभाग, त्रिभुवन विश्वविद्यालय **(CENTRAL DEPARTMENT OF BOTANY, TRIBHUVAN UNIVERSITY)**:- जानकारीको लागी अनुरोध छ।
श्री सर्व-डिभिजन वन कार्यालय, लेटाङ्गः आवश्यक सहयोग गर्नु हुन।
श्री राजारानी सामुदायिक वन उपभोक्ता समुह, लेटाङ्गः आवश्यक सहयोग गर्नु हुन।

नेपाल सरकार
वन तथा वातावरण मन्त्रालय
वनस्पति विभाग

राष्ट्रिय हर्बेरियम तथा वनस्पति प्रयोगशाला

पत्र संख्या: ०८३/०८०
च.नं. २६८

गोदावरी, ललितपुर

मिति २०७९/१०/२२

विषयः नमूनाहरु पहिचान सम्वन्धमा।

श्री प्रमिला गच्छदार,
त्रिभुवन विश्वविद्यालय,
कीर्तिपुर, काठमाडौं।

प्रस्तुत विषयमा तपाँइको मिति २०७९/०४/२९ को निवेदन साथ वनस्पतिहरुका नमूनाहरु प्राप्त भई व्यहोरा अवगत भयो। पत्र मार्फत ल्याइएका नमूनाहरुको पहिचान गरी प्राविधिक विशेषज्ञको प्रतिवेदन (पाना १) यसै पत्रसाथ संलग्न गरी पठाइएको व्यहोरा अनुरोध छ।

२०७९/१०/२२

हेम राज पौडेल
अनुसन्धान अधिकृत
(१८२५६१)
नि.कार्यालय प्रमुख

फोन नं.: ५१७४२७७, ५१७४०४७, फ्याक्स: ९७७-०१-५१७४३४९, पोष्ट बक्स नं.: ३७०८
Website: www.kath.gov.np