FLORAL SPECIES RICHNESS PATTERN IN ARGHAKHANCHI AND ADJOINING AREAS, 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
BABURAM NEPALI
DECEMBER, 2023

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TRIBHUVAN UNIVERSITY
Institute of Science and Technology
DEAN'S OFFICE
Kirtipur, Kathmandu, Nepal

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DECLARATION

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

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

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LETTER OF APPROVAL

Date: 13/12/2023

On the recommendation of Associate Prof. Dr. Chitra Bahadur Baniya (supervisor) and Dr. John Skartveit (co-supervisor), this Ph.D. thesis submitted by **Baburam Nepali** entitled "**Floral Species Richness Pattern in Arghakhanchi and Adjoining Areas, Nepal"** is forwarded by Central Department Research Committee (CDRC) to the Dean, IOST, TU.

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ABSTRACT

The biodiversity and their pattern may vary from a broad geographic area to a small local scale due to changes in their linked components along spatial and temporal gradients. Basic knowledge of distribution, diversity, and roles is necessary for the conservation of any group of organisms. In this synthesis I examined the variations in species composition and richness patterns over various spatial gradients and how they relate to the nutrients found in the low mountainous regions of west Nepal.

This thesis is based on field-survey data of vascular and lichen species, analyzed soil data as well as secondary data from published articles. The study is mainly focused on vascular plant as well as lichen species composition, richness and soil heterogeneity, which is based on direct field sampling in national and community forest of Arghakhanchi and adjoining area: Resunga forest of Gulmi district, Nepal, to compile baseline information. The survey was done in autumn and spring seasons for two consecutive years (2018-2019) at various elevations that varied from 200 to 2300 m. The primary data of vascular plants was collected by use of 10 X 10 m quadrats in stratified random sampling design along the elevational gradient. From the same sampled plots, lichen specimens and soil samples were also collected. The soil samples were chemically analyzed in laboratory. The vascular and lichen specimens were identified by comparing with already identified herbarium specimens and by following identification keys. The data was analyzed by use of various statistical techniques: Generalized linear model (*GLM*) regression, PerManova, DCA and CCA ordinations in R software. The elevational diversity indices (Shannon-Wiener, Simpson and Pielou's evenness) of plant life forms were estimated.

A total of 606 species of vascular plants and 47 species of lichens were found in the field. Plant life forms classified by Raunkiaer (1934) yielded the following results: 265, 37, 158, 57, and 89 species for Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes, and Therophytes, respectively. According to the different types of forests, the mixed pine forest containing *Schima wallichii, Castanopsis indica, Pinus roxburghii* obtained the highest vascular species richness. C*apillipedium assimile* is the species which obtained bear the highest Important Value

Index in all three ecological regions (Tropical, Sub-tropical and Temperate). The regression results show that all vascular plants, life-forms species and lichen species follow the statistically significant elevation-dependent unimodal structure. Unimodal pattern is found as common elevational species richness pattern, but is not compulsory pattern against elevation in small areas.

The explanatory factors show a stronger influence on species composition than species richness, according to correlations and canonical correlations. The Hemicryptophytes, Phanerophytes and Therophytes had significant positive relationships with elevation and soil nitrogen, whereas the Chamaephytes, and Geophytes, had a negative relationship. Elevation and nitrogen function show the uniqueness of the interplay between life forms by acting as key factors of plant dispersal. Other factors-RRI, soil pH, phosphorus, potassium show comparatively less impact in species composition.

According to the appearance of a peak in species diversity at nearly the same elevation and a pattern that is similar, the diversity of vascular plants promotes the abundance of lichens. The diversity of lichens was strongly correlated with the habitat and elevation than the aspect of hills. At all levels of spatio-temporal gradients, species richness and composition patterns are strongly scale dependent. Certain variables, such as soil-related local-scale heterogeneity and slope aspect, are essential for figuring out species composition and richness trends.

Based on our results, it is cleared that the study area: Arghakhanchi district and its adjoining areas provide variable habitats for vascular as well as lichen community. Open ground floor is mainly rich in native as well as alien herb plant species, which are less dominant in forests. It is cleared that species composition is a more useful tool in landscape ecology and biogeography research than species richness. Therefore, plant community structure should be used as a reliable and insightful indicator in biogeography studies and conservation planning.

Keywords: Arghakhanchi, Churia hill, Lichen**,** Lowland Himalaya, Species composition, Soil nutrients, Vascular plants

शोधसार

भौगोलिकता र समयसँग सम्बन्धित विभिन्न कारक तत्वहरुले गर्दा जैविक विविधता र तिनीहरुको संख्याका ढाँचाहरु क्षेत्र अनुसार फरक फरक हुन्छन् । कुनै पनि वनस्पति तथा जीवजन्तुहरुको संरक्षणको लागि उनीहरुको विविधता, प्राकृतिक वितरण र महत्व सम्बन्धी जानकारी हुनु अनिवार्य हुन्छ ।

यो अनुसन्धान कार्यको मुख्य उद्देश्य पश्चिम नेपालका होचा पहाडहरुमा पाइने वनस्पति प्रजातिहरु मुख्यतया भास्कुलर विरुवाहरु (Vascular Plants) र झ्याऊ (Lichen) को संरचना, फैलावट र अन्य कारक तत्वहरुसँगको सम्बन्धको अध्ययन गर्नु हो । यसका लागि अर्घाखाँची जिल्ला र योसँग जोडिएको गुल्मी जिल्लाका केही भागमा रहेका राष्ट्रिय तथा सामुदायिक वनमा अनियमित स्तरीकृत (Stratified Random) नमूनाको ढाँचा अनुसार १० x १० m^2 को प्लट प्रयोग गरी विरुवाका नमूनाहरु र माटो सङ्कलन गरियो । प्रयोगशालामा माटोको परीक्षण साथै सङ्कलित विरुवाहरुको पहिचान सम्पन्न गरियो । प्राप्त तथ्याङ्कलाई Generalized Linear Model, PerManova, DCA र CCA को प्रयोग गरी विश्लेषण गरियो ।

यो अनुसन्धान क्षेत्रमा भास्कुलर विरुवाहरु (Vascular plants) र झ्याऊ (Lichen) का क्रमश ६०६ र ४७ प्रजातिहरु पत्ता लगाईयो । सन् १९३४ को Raunkier को वर्गीकरण अनुसार Phanerophytes Chamaephytes, Hemicryptophytes, Geophytes, र Therophytes का क्रमशः २६५, ३७,१५८,५७ र ८९ प्रजातिहरु भएको पाइयो । चिलाउने, कटुस, रानीसल्ला भएको जङ्गलमा बढी जैविक विविधता र मुसेखरीको *(Capillipedium assimile)* को बढी IVI Value प्राप्त भयो ।

झ्याऊ र भास्कुलर विरुवाहरु (Vascular plants) को संख्याको उचाईसँगको सम्बन्ध जुरे आकारको (Hump Shaped) पाइयो । तर यस्तो सम्बन्ध कम उचाईको दायरामा कायम रहेन । विभिन्न अजैविक कारक तत्वहरुको सम्बन्ध प्रजातिहरुको संख्या (Species Richness) भन्दा तिनीहरुको संरचना (Species Composition) मा वढी भएको देखियो । त्यस्तै उचाई र माटोमा भएको नाइट्रोजनले अन्य कारक तत्वभन्दा वनस्पति प्रजातिहरुको वितरणमा बढी भूमिका खेलेको पाइयो । झ्याउ प्रजाति र भास्कुलर (Vascular) प्रजातिको उचाईसँगको सम्बन्धको रेखाचित्रको शिखर (Peak) करिब एकै उचाईमा पाइएकोले भास्कुलर काठका प्रजातिहरु बढी भएको ठाउँमा झ्याऊ प्रजातिहरु बढी सङ्ख्यामा पाइन्छन् भन्न सकिन्छ ।

अन्त्यमा अर्घाखाँची र आसन्न क्षेत्रहरु भास्कुलर र झयाऊ प्रजातिको वितरणको लागि उपयुक्त देखिनुका साथै यिनीहरुको उचाईसँग गैररेखीय (Non Linear) सम्बन्ध रहेको देखिन्छ । प्रत्येक विश्लेषकीय कारकतत्वको प्रत्येक प्रजातिसँगको सटिक सम्बन्धको व्याख्या गर्नको लागि विस्तृत अनुसन्धानको आवश्यकता देखिन्छ ।

मुख्य शब्दहरु: अर्घाखाँची, चुरेपर्वत, झ्याऊ, होचा पहाडहरु, प्रजाति संरचना, पोषक तत्व, काष्ठ र गैरकाष्ठ विरुवाहरु

LIST OF ACRONYMS AND ABBREVIATIONS

BCN	: Bird Conservation Nepal
BS	: Bikram Sambat (according to Nepali Calendar)
CBS	: Central Bureau of Statistics
CCA	: Canonical Correspondence Analysis
Cham	: Chamaephytes
DHM	: Department of Hydrology & Meteorology
DFO	: District Forest Office
DCA	: Detrended Correspondence Analysis
DoF	: Department of Forests
Ele	: Elevation
FECOFUN	: Federation of Community Forestry Users Nepal
Geo	: Geophytes
IVI	: Importance Value Index
Hemi	: Hemicryptophytes
MeanT	: Annual Mean Temperature
MixCon	: Mixed Conifer Forest
MixPin	: Mixed Pine Forest
Phan	: Phanerophytes
QueRho	: *Quercus-Rhododendron* forest
RRI	: Relative Radiation Index
Sq. km	: Square Kilometer
Ther	: Therophytes
TotR	: Total Annual Rainfall

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ANNEXES I

1. INTRODUCTION

1.1 Background

1.1.1 Floral Diversity

Floral diversity is the variety of entirely plant species that are/were existing in a particular area during a certain time. It is also called "plant diversity" and is a main part of biodiversity or biological diversity. Biodiversity refers to three aspects of life: ecosystem diversity, species diversity, and genetic variation within species (UN, 1992). Although W.G. Rosen coined the term "biodiversity" in 1985, E. Wilson (1988) was the first to use it to refer to all sorts of diversity (Sarkar, 2021). Long earlier, the study of biodiversity was used in many disciplines: such as biology, medicine, and Ayurveda (Mayr**,** 2000). Therefore, ancient research on floral or plant diversity served as the foundation for the origin of the new subject of biodiversity.

From the earliest microscopic archaea bacteria to eubacteria and cyanobacteria, unicellular algae to multicellular algae, aquatic bryophytes to terrestrial gigantic gymnosperms and angiosperm plants, the development of plants has produced a vast spectrum of complexity. The fossil records show the occurrence of embryophyte land plants is dated the mid-Ordovician and the middle of the Devonian (~390 million years ago) period. Many of them were similar to present plants having characteristics such as roots and leaves (Rothwell *et al.*, 1989). There are estimated 374,000 plant species present on Earth. Among these, 308,312 species are vascular floras, with 295,383 angiospermic plant species in the biosphere (Christenhusz & Byng, 2016).

Biodiversity is essential to maintain human livelihoods because it provides ecosystem services and carbon sequestration. It also supports some "nature-based solutions" to problems brought by environmental changes and climate change. The species that live in a certain area are connected and dependent on one another to survive (Tang, 2020). In 1735, Linnaeus assumed that everything belonged to an unchanging species created by god. Georges Buffon believed that geography, climate, and even species and nature were all dynamic and subject to change (White, 2011). Augustin de Candolle (1805) studied plant disper through water, wind, and animal activity up until they encountered barriers like the sea, desert, or mountains and the first time used the term "endemic". Alfred Russel Wallace stated that closely related species were frequently located geographically adjacent to one another. "Theory of natural selection" projected by Darwin and Wallace in 1858, served as the fundamental paradigm for biological sciences. Adolf Engler drew the first map of the world's vegetation in 1879 (Charles, 1978). Biogeographers had previously attempted to analyze historical biogeography in light of several geological eras, such as the Carboniferous, Permian, and so forth.

The field of ecological biogeography was expanded by contemporary genetics or modern genetic science in the 20th century. After finding the evolution of plants and animals, Clements and Shelford (1916) first proposed the idea of a biomes. It was focused on the taxonomic or phylogenetic component of its plant constituents, which seems to the Takhtajan's "floristic regions". Christen Raunkiaer derived his theory of plant life forms, which is based on how plants can survive from one growing season to the next, which had a tremendous impact on plant geographical study (Danin & Orshan, 1990). In the 20th century, a new discipline emerged named ecophysiology—the study of how floras and faunas differ in their physiological processes in reaction to the environment. Biogeographers will benefit from improvements in physiological research as well as ecological and behavioral studies to better understand the environmental requirements and ecological niches of creatures within ecosystems. The niche concept, first proposed by G.E. Hutchinson in the 1950s, is now a significant advancement in ecology and biogeography. Furthermore, ecological biogeography has expanded its research from local to larger scales of analysis and in the practical application of its results to the most pressing global challenges. James H. Brown proposed Macroecology, in 1995 for ecological problems that required extensive study. Climate change, range shifts, variation in pattern, and assessments of ecological complexity can all be subject to statistical and mathematical analysis on a larger scale than is often used by experimental ecologists (Brown, 1999).

1.1.2 World’s Floral Diversity Patterns

Earth has been created by combination of different things, interacting with one another, which confined in plants and animals distribution within the areas in which they evolved. Most of species have limited range of environmental conditions to survive. Variation in species richness is a common process and speciation occurs by two methods: parasympatric and allosympatric (Safran & Nosil**,** 2012**).** The sources of genetic diversity are: mutation, recombination and immigration of genes are the basis of origin of new species (Maia & Campos, 2021). Biome types that are more common at higher latitudes and are also typically found at greater elevations. So, it can be said that rising elevation would replicate the patterns of biodiversity found throughout the world, which decrease from the equator to the poles. Ecologists and bio -geographers most usually evaluate biodiversity as species richness, in spite of the fact that it's three ranks of organization: ecosystem level, species level and genetic level. Just 5% to 10% of the biosphere's species have been idenfined, while 91% of the species in the sea and 86% of the species on land still require description (Mora *et al.,* 2011).

Previous biologists specially looked at morphological traits, habitats, or habit forms while studying biodiversity. Aristotle made the earliest attempts to categorize plant and animal life forms, while Theophrastus identified tree, shrub, and herb plant habits in his *Historia Plantarum* (about 350 BC) (Niklas, 2008). Warming coined the phrase "life-form" in 1895, but the book "*Oecology of plants,*" published in 1909, translates it as "growth form." (Warming, 1909). Initial classifications were based upon plant-form. Now, species is frequently used in biodiversity studies. Numerous climatic, edaphic, and topographical factors influence on species diversity and species richness (Pandey *et al*., 2020).

The biodiversity is unevenly distributed throughout the earth due to variation in latitude, elevation topography and other related factors (Gaston, 2000). Numerous interrelated elements, such as ecological factors, antagonism, geographic location, and past/evolutionary change have an impact on patterns of species variety and abundance on a universal scale (Criddle *et al.,* 2003). The longest-recognized configuration in biodiversity is the latitudinal gradient of dwindling abundance from tropical to polar areas (Willig *et al*., 2003). About 44% of entire vascular plant species are concentrated in just 25 hotspots, or 1.4% of the terrestrial surface of earth (Myers *et al*., 2000). Tropical rain forests are thought to be the world's largest biodiversity hotspots since they are home-grown to more than half of all identified species while taking up only 7% of the planet's surface area (Wilson, 1988). But there is less topographical and climatic variation in comparison to Himalaya region. With an estimated 3,160 endemic angiosperm species or approximately 31.6% of endemic species (Rana *et al*., 2019), Himalayas in Asia actually provide the world's most delicate ecology and are a rich source of biodiversity. Geographically, it varies from wide, perpetually snow-covered regions at higher elevations of 8,848 m to warmer regions at elevations lower than 100 m (Das & Bera, 2018). Therefore, investigations on mountain elevational patterns have been increasingly popular in recent study of both flora and fauna patterns.

According to the presumption that the elevational gradient is the reflection of the latitudinal gradient, species richness is predicted to monotonically decline as elevation rises. But, more than 50% of studies on elevational species abundance exhibits a unimodal outline having a mid-elevation peak, whereas 25% of studies reveal a monotonic ascent and the other studies reveal a monotonic decline (Rahbek, 1995, 1997). As it is known, there is an incredibly universal tendency for species numbers to increase and decrease as a region changes. According to Lomolino (2001), the actual species-area relationship may be far more complex (Sigmoid or curved).

Mountains, contain the highest biodiversity, have the longest elevational gradient, and noticeable variations in environmental gradient on a small geographic scale, making them the best places to study trends in elevation biodiversity (McCain & Grytnes, 2010). It has become a biodiversity hot point of major worldwide significance due to climatic and topographical variance combined with a vast variety of habitats occupied by fauna and flora species (Meyers *et al.,* 2000; Wambulwa *et al.,* 2021). Until now, 10,503 herbal species from 240 families and 2322 genera have been recognized in the Himalayan area (Rana & Rawat, 2017). The Himalaya's species richness declines by three times from east to west, showing that its eastern region has more biodiversity than its western region.

The species abundance of vascular plants frequently exhibits a hump-shaped tendency along the elevational ascent in the Himalayas (Liang *et al*., 2020) and the most of the other factors are determined by elevation. The previous studies: Climate factors (McCain, 2006, 2009; Kluge *et al*., 2017), rainfall (Evans *et al.,* 2004; Asfaw *et al*., 2020) surface curvature and slope aspect in south China (Wang *et al*., 2015), soil variables: pH, nitrogen, phosphorus: and sulfur (Zhang *et al*., 2017), spatial factors (Changbae *et al*., 2013; Wu *et al*., 2013; Hu *et al.,* 2017), ancient facts (Feng *et al*., 2017; Hu *et al.,* 2018), habitat complexity (Karr & Roth, 1971; August, 1983), and disturbance factors (Pan *et al*., 2019), etc. have all been projected to explain the elevational species richness patterns. The factors related to weather, especially energy (e.g., temperature) and water (e.g., precipitation), are the greatest maintained description in expressions of both elevational and latitudinal trend species abundance (Rhode, 1992; Hawkins *et al*., 2003; Currie *et al*., 2004; Kreft & Jetz, 2007). But, unimodal patterns are a conditional rule in community ecology, according to Graham & Duda (2011).

1.1.3 Floral Diversity and its Patterns in Nepal

Nepal has a unique type of biodiversity due to the presence of great elevation variation (from 58 to 8848.57 m) within a short distance and the presence of ecological zones ranging from warm, tropical to cold, alpine. So, most of the factors which play major role in biodiversity distribution are determined by elevation in Nepal. It is ridiculous in biodiversity having a total of 1001 species of Algae (Prasad, 2013), 2,182 types of Fungi (Kost & Adhikari, 2015), 1078 lichen species (Baniya et al., 2022), 1213 species of Bryophytes (Pradhan, 2016), 580 species (550 species and 30 subspecies) of fern and fern allies (Fraser-Jenkins *et al.,* 2015), 41 gymnosperm species (Shrestha *et al*., 2018) and 5309 species of angiosperms (Rajbhandari *et al*., 2017) even though it occupies 0.03% of world landmass (Chaudhary, 1998).

According to earlier studies, the plant and animal species of Nepal was initially explored by foreign researchers. Lack of experts, the required equipments and technology, and lack of the required funding were the main contributors to this. Kirkpatrick began the botanical exploration of Nepal in 1793 from Terai, Birgunj to Kathmandu, and other foreign experts such as Hamilton (1802), Wallich (1820), Sir J. D. Hooker (1948), Banergy (1948), and Wollaston (1922) continued his work from the Kathmandu valley and the lower and higher Himalayas in the east of Nepal. Later, several foreign and Nepalese explorers carried out both solitary and group searches in the sub-alpine and alpine regions at various times to study the flora. These exploration investigations, however, did not consider the relationship between elevation and other parameters, simply the biodiversity.

On the basis of earlier research findings, Nepal's elevational species richness trend is taxon dependent. Most investigations on vascular plants revealed a hump-shaped pattern (Rahbek, 1995 & 1997; Naqinezhad *et al*., 2014; Vetaas & Grytness, 2002;

Bhattarai & Vetaas, 2003; Subedi *et al*., 2015; Pandey *et al*., 2020). Other taxonomic groups, including lichens (Baniya *et al.,* 2010), orchids (Acharya *et al*., 2011), fern (Bhattarai *et al*., 2004), and bryophytes (Grau *et al*., 2007) also produced an elevational hump-shaped pattern**.** The main cause of the variations in observed patterns may be climate factors like water and energy availability as well as edaphic.

Most of the biological studies in Nepal is focused on overall species richness rather that species composition along with discrepancy in elevation, topography, soil composition and other factors. There are less focused in relation to soil composition with species composition, relation of vascular plant with other non-vascular plants along with elevation. Ecological studies have revealed this as a hidden aspect that high vascular plant diversity promotes lichen variety. The relationship between plant variety and differences in soil nutrients throughout wide spatial gradients at a large scale has not yet been fully investigated.

Nepal is one of the cosigners of the Earth Summit on Living diversity held in Rio de Janeiro (1992). That indicated a strong commitment and support for the conservation, identification and supportable practices for biological conservation. Thus, proper identification of all biological properties at all scales of nature is the prime responsibility of each Nepali to fulfill norm of that signatories. In this regards, each natural landscape of Nepal is equally important to know their biodiversity and the distribution pattern.

1.1.4 Rationale

Nepal has a unique type of physiography and the largest elevational variation within the short vertical distance (about 150 km) and a variety of habitats is found in the Himalayas of Nepal (Dobremez, 1976). The study of flora and wildlife has long been drawn to this tiny geographical area of Nepal, which serves as a transitional area between the Eastern and Western Himalayas (Takhtajan, 1978). Armen Takhtajan, a famous botanist (1949) stated that the western Himalayas, the area situated westwards of Kaligandaki River gorge (the world's deepest valley) in central Nepal is one of the biogeographic realms of the world. Many floristic expeditions conducted here were by the Japanese. Thus, this present research has been initiated to fill up the gap of plant species diversity pattern from the less explored western Himalayan region in general and two landscapes of Arghakhanchi district and its adjoining areas, West Nepal in specific.

Various national and international groups have conducted numerous trips throughout Nepal, focusing on the nation's subalpine and alpine regions. Similarly, many ecological studies which cover the species richness pattern studies in Nepal are focused on long elevation range: 792 to 7245 m in Langtang NP (Dahal, 2011), bryophytes in 100-5500 m (Grau *et al*., 2007), less than 1000 to 8091m (Khanal, 2020), trees in 550-2500 m in Hetauda (Bhattarai *et al*., 2018). The outcomes of earlier works indicate that the biodiversity of low mountains specifically tropical and Sub-tropical regions does not receive much scientific attention. Thus, this present research has initiated to fill up the gap of baseline plant information and to find out the species diversity pattern from the less explored western Himalayan region in general and particularly lower mountains like Arghakhanchi district and adjoining areas in specific.

Numerous ecological studies that have concentrated on the pattern and species composition have concluded that the elevation is the most crucial ecological factor that determines the pattern and species composition. However, the precise components that give rise to a given type of pattern have not been identified yet. This research identifies the critical element that influences on elevational richness pattern and demonstrates the relationship between environmental factors and species composition. Elevation is highlighted as single confounder of elevational species richness pattern. But, reasons behind it not sufficient.

1.1.5 Limitations of the Study

a) The study region primarily includes the tropical and subtropical region of the Himalayan Mountains and their low-elevation biomes. There are frequent land slides and firing and great degree of deforestation owing to increasing human actions and domestic animal grazing. The role of anthropogenic factors on species distribution is not covered.

b) The plant species present only inside sampled area (quadrats) are included for analysis in this study.

1.1.6 Hypotheses

The hypothesis proposed of this research work is:

a. "Plant species richness follows unimodal patterns of plant species richness along elevation gradient."
b. “Lichens species also follows similar unimodal pattern as higher plants along elevation.”

1.1.7 Research Objectives

1.1.7.1 General objective

To decipher the elevational plant species richness, and species composition pattern in Arghakhanchi and adjoining areas (Resunga forest) of Gulmi district.

1.1.7.2 Specific objectives:

1. To know the vascular plant diversity and its elevational species richness pattern
2. To study the association among vascular plant species, and ecological factors: {Elevation, RRI (Relative radiation index), soil pH N, P, K and slope aspect} along elevational gradients.
3. To know the lichen diversity and its relationship with environment.

1.1.8 Thesis outline

In the thesis, every research question is answered in a separate chapter. There are many vascular plant and lichen’ taxa that provide important role in community ecology. It is not possible to cover them all. Thus, only vascular plant species (angiosperms, gymnosperms, and pteridophytes) and lichen species which were present in the sampled plots are the subject of this study.

Chapter 1 summarizes the overall introduction of the thesis, the significance of the study, the key objectives, the thesis outline, conceptual framework of research work (**Figure 1**) and detail information (location, vegetation, climatic situation and population status) of districts: Arghakhanchi and Resunga of Gulmi district of study area.

Chapter 2 contains overall species composition and vegetation analysis of vascular plant present in study area. The species alignment were pronounced on the basis of taxa, on the basis of Raunkiers’ life form category (1934), and the proposed forest types. 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, coverage and important value index (IVI).

Chapter 3 focuses on the plant species - environment relationships. Over a two-year period (2018–2019), the basic plant data was gathered and the soil nutrients from the soil sample were examined in a laboratory. Results using generalized linear model regression, Pearson correlation, PerMANNOVA, and ordination demonstrated the relationships.

Chapter 4 includes the diversity of lichens as a whole, lichen species according to habitat type, elevational pattern of lichen species and lichen-host relationship. The high diversity of vascular plants favors higher lichen diversity, as seen by the lichen and host (shrub and tree) species regression curves.

Chapter 5 highlights the discussion of chapter 2, 3, and 4. It also tries to synchronize among the floral diversity, lichen diversity and their relationship with environment.

Chapter 6 summersize the findings of the all chapters and provides conclusion of work. It also provides recommendation and management guidelines for this area.

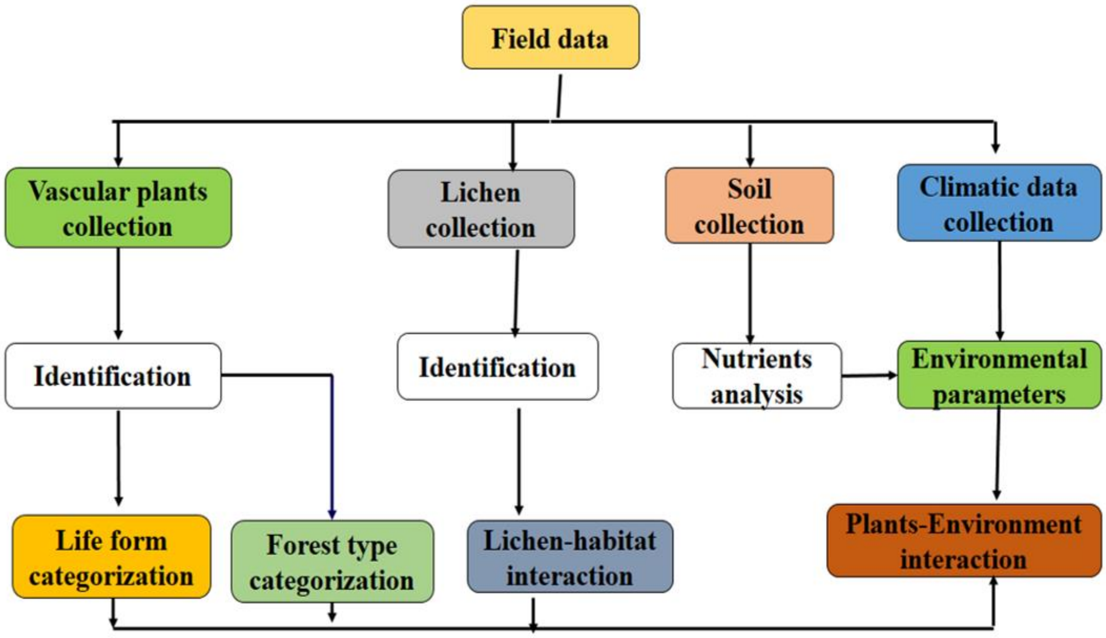


Figure 1: Conceptual framework of research work

1.2 Study Area

The Arghakhanchi district and adjoining areas in western Nepal was the site of this study. It denotes that it covers the entire Arghakhanchi district as well as its neighboring region, the Resunga municipality of the Gulmi district in the north site. There are two landscapes in Arghakhanchi district: Narapani-Masina landscape and Resung-Malarani landscape. Out of these two, Resunga-Malarani landscape is extended in both Arghakhanchi and Gulmi district.

1.2.1 Arghakhanchi district

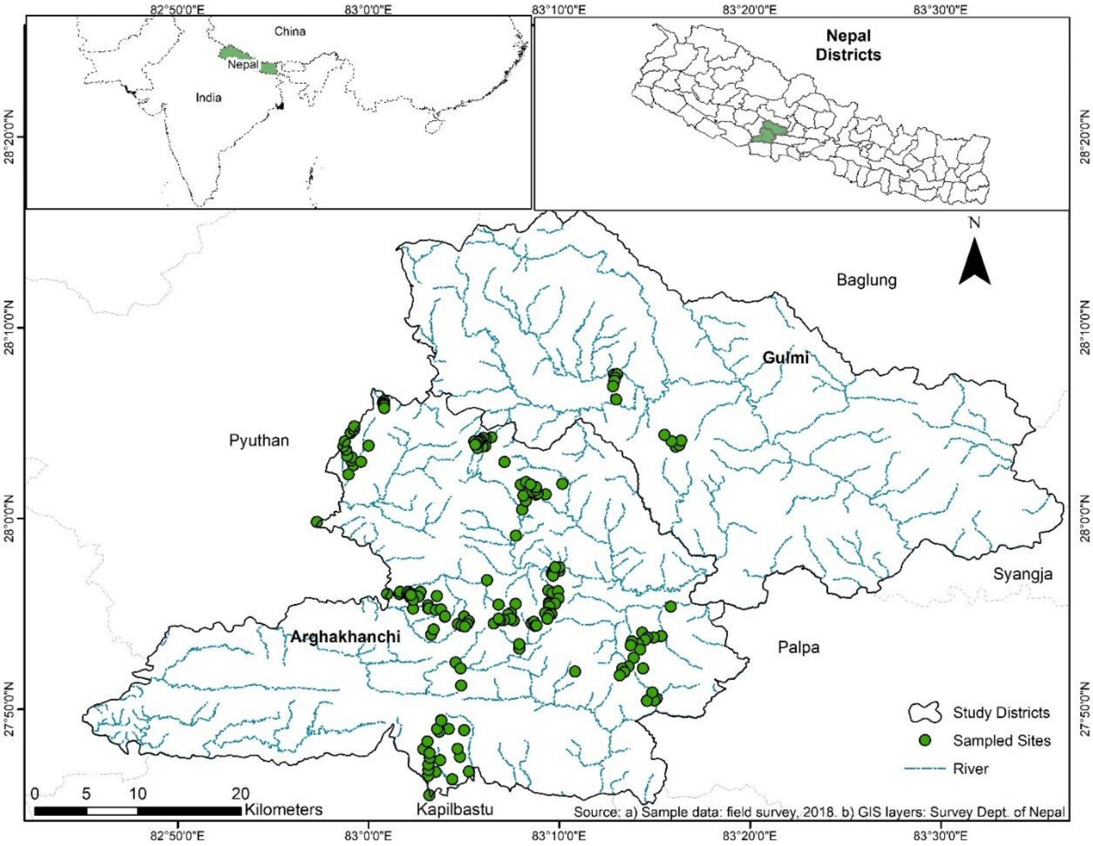
1.2.1.1 Geographical situation

Arghakhanchi, a mountainous districts, is located in Lumnini Province, west part of Nepal. Its latitude and longitue range from 27º45' - 28º06'N and 80º45' - 83 º 23' E respectively (**Figure 2**). Its space is 1193 km² and inhabitants is 197,632 (CBS, 2021). The Mahabharat range and Siwalik Hills ocuupy about 68 % and 32% area of this district. The elevation ranges from 240 to 2515 m in Arghakhanchi (AEPC, 2016). Ecologically, this district has four zones: lower tropical (less than 300 masl), higher tropical (300-1000 masl), sub-tropical (1000-2000 masl) and temperate zone (more than 2000 masl) which cover 2%, 51%, 49% and 2% land of total district (CBS, 2021).

In total 119,300 ha land of Arghakhanchi, cultivable land conquers 45,712 ha (38 %), afforested land covers 66,800 ha (56 %), wetland lodge 5768 ha (4.8 %) and the inhabited area covers 1020 ha (0.85 %) (MoAC, 2011).

1.2.1.2 Climatic condition

On the basis of two climatic stations: Khanchikot and Tamghas present in Arghakhanchi and Gulmi districts, the annual mean temperatures range remains between 16-18 °C in Arghakhanchi and 12-14°C in Gulmi district (DHM, 2021). There was great variations in rainfall and maximum annual rainfall (about 2500 mm) recorded in 2013 in Tamghas station (**Figure 3**.). There is other one climatic station: Sandhikharka as well as two rainfall stations at Nipane, Narapani and Rangsing in Arghakhanchi district.



Source: a) Sample data: field survey, 2018. b) GIS layers: Survey Dept. of Nepal

Figure 2: Map of study site (Arghakhanchi district and its adjoining area) with sampled sites

1.2.1.3 Vegetation

The south part of Arghakhanchi district is connected to Terai region (Rupandehi and Kapilvastu district). So, lower south belt (300-1000 m) of Masina-Narapani landscape is dominated by lower tropical forest of *Shorea robusta.* Other associated species are: *Dalbergia sissoo, D. latifolia, Lagerstroemia parviflora, Terminalia alata,* etc. In the mid belt (above than 1000 m), hill *Shorea* forest is mixed by *Schima wallichii, Castanopsis indica*, *Syzygium cumini*, *Pinus roxburghii*, and *Pyrus pashia*. There is dense form of *Diploknema butyracea*, which is mixed with *S. robusta* in lower belt and with *Castanopsis tribuloides*, *Xylosma longifolia* and *Schima wallichii* upper belt in the western part of Narapani-Masina landscape.

In the north side (below 1500 m), the broad-leaved forest (*Diospyros malabarica, Rhododendron arboreum, Castanopsis indica, Schima wallichii*) is combined with *P. roxburghii* and *S. robusta*. Broad-leaved forest (*R. arboreum, S. wallichii, P. roxburghii, Myrica esculenta)* is existing beeween 1500-2000 m. In some places, *Pinus roxburghi* patches is totally replaced to other species. The topmost area (above than 2000 m), the *Quercus-Rhododendron* - *Maesa* mixed forest is present which

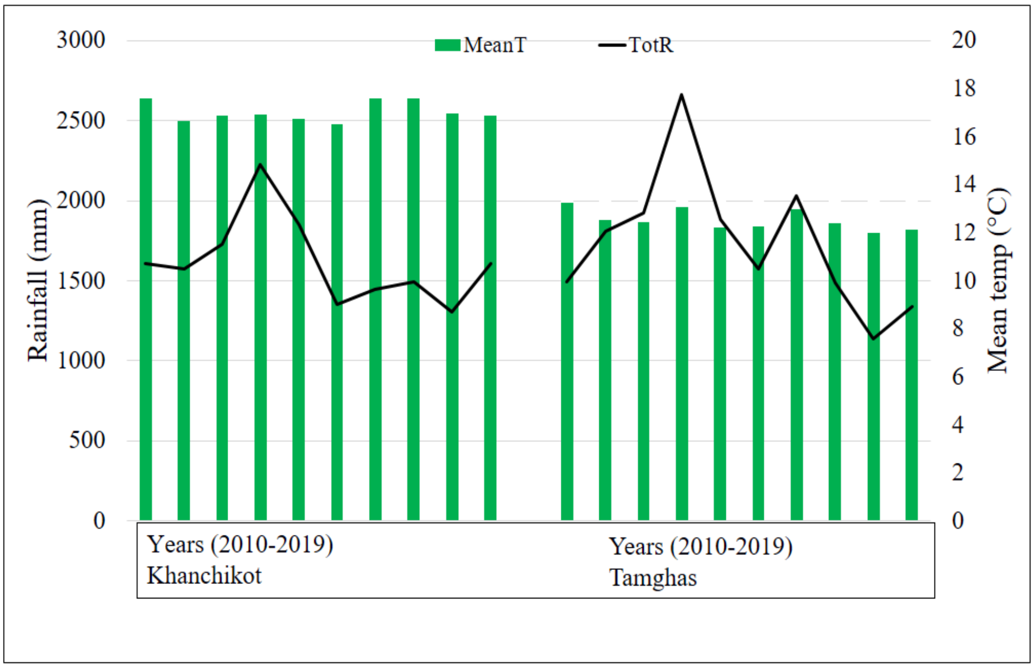


Figure 3: The mean temperature (MeanT) (ºC) and Annual rainfall (AnnR) (mm) recorded in (**A**) Khanchikot (1801 m), and (**B**) Tamghas (1530 m) from 2010-2019

consist the main species: *M. esculenta*, *R. arboreum*, *Q. semecarpifolia*, *Q. glauca*, *Zanthoxylum armatum* with scrublands of *Berberis asiatica*, *Maesa chisia*, *Xylosma* etc. (Panthi, 2005).

1.2.1.4 Population

The population of Aghakhanchi district is 177,200 and population density is 149 per sq.km. The population status shows that population of this district is declining at rate of 1.09% each year (CBS, 2021). The search of education facilities, occupation, fertile land etc. are main cause of this emigration from this district.

1.2.2 Gulmi district

1.2.2.1 Geographical situation

Gulmi is adjoing mountainous district of Arghakhanchi, which is situated in Lumbini province. It is bounded by Syangja and Parbat district on the east, Palpa, and Arghakhanchi on the south, Baglung on the north, and Pyuthan on the west. It is popular for coffee agri-business and is a main exporter of organic coffee. Gulmi district bears the area of 1,149 km^2 and geographically it extends from 83° 01’ - 84° 37’ E longitude and 27° 55’- 28° 16’ N latitude (CBS, 2021). It has a surface size of 13,761 acres with an elevation range of 465 m (Ridi) to 3050 m (The top of Thaple).

The main river is Kaligandaki, which is originated from the Himalayas. Other small rivers are: Badigadh, Challikkhola, Nisti, Hugdi, Ridi, Daram khola and Panaha khola which originate from hills.

1.2.2.2 Vegetation and Climate

There are three categories of climate zones: tropical (< 1000 m), subtropical (1000-2000 m) and temperate (> 2000 m) (Lillesø *et al*., 2005) which cover 23.5%, 71.9% and 4.6% area of total Gulmi district. The land-living pattern of Gulmi district expresses that farming land covers 657.23 sq km, (i.e., 57.2% of total land) and it is tracked by woodland (38.1% or 437.77 sq km).

Resunga is located in the Gulmi district and spans a 3400 ha area between elevations of 560- 2300 m. (Sharma *et al.,* 2015). In the Resunga section, there are 252 watersheds which are primary basis of drinking water for the residents (Panthi, 1984). Resunga is famous for religious site as well as a historical pilgrimage site. It is also source of watershed, and biological diversityand famous for tourist attraction within the nation, due to beautiful recreation area surrounded by lush vegetation (Acharya, 2012).

Resunga is gorgeous in plant diversity, which is a habitas of varied wild animal and consist of Sub-trop and temperate forests. Eighteen community forests of surrounding region cover 1973.93 ha in total forest (3400 ha). Similarly, the Resunga religious forest (sacred grove) covers 165.17 ha and the remaining area is under control of government (DFO, 2014). The dominant trees present in the area are: *Quercus semecarpifolia, Alnus nepalensis, Camphora glandulifera, Pinus roxburghii, Schima wallichii* and *Rhododendron arboreum.*

1.2.2.3 Population

The population of Gulmi district is 246,436 (CBS, 2021) and population compactness is 210 per sq.km. The population decreasing level of this district is 1.12% per year. The main cause of the decrease of population may be emigration in search of education facilities, occupation, fertile land as well as the facility of health and low birth rate etc.

2. VASCULAR PLANT DIVERSITY

2.1 Introduction

Biodiversity or floristic diversity means the variation in ecosystem, species and genetic diversity of any particular place (Wilson, 1988). Biodiversity is popularly expressed in species diversity as well as species composition. The species diversity is variable according to geographical feature, place, elevation, aspect, season, slope, time etc. Biodiversity is the amount of total biotic dissimilarity from the gene level to ecosystems level.

There are various methods to measure the biodiversity. The best measure of biodiversity is through species richness. Biodiversity measurement or biodiversity parameters affect ecological stability (Yadav & Mishra, 2013). Different types of environmental factor show great variation in species richness in any place and topography plays greater role by changing in different factors: elevation, slope, aspects, temperature, humidity etc. Finding a quantifiable assessment of biological variability is the fundamental goal of a diversity index, which can be used to compare biological entities made up of discrete components over time or place (Heip *et al.,* 1998). Evenness reflects how equally the members of the community are divided across the various species, whereas species abundance measures the overall figure of species in the communities.

According to Warming (1909), a life-form is a representation of the synchronization between a plant and its surroundings since it represents the total of a species' adaptive characteristics. Though it is projected that there are between 5 - 30 million species on world, simply 1.2 (-1.9) million has been revealed, named, and catalogued **(**Kunzig, 2008; Mora *et al*., 2011). Only 5- 10% of the species have been documented to far, and 86% of the teretrial species and 91% in the ocean are yet to be described (Mora *et al*., 2011). Due to the dramatic variety in elevation and topography, as well as other elements impacted by them, the Himalaya is considered to be a large storehouse of terrestrial species. There is the longest elevation range (< 60- 8848 m) and unique topography in Nepal including hot plains, jagged hills and perennially wind regions which may favor for unique plant and animal species found in tropical to nival regions. In general, endemic richness grows proportionately with elevation, which encourages isolation and speciation of species in the Nepal Himalayas, however endemic species diminish above roughly 4000 (3500–4500) m due to a rapid fall in species richness (Vetaas & Grytness, 2002).

Sir Francis Buchanan-Hamilton, a British naturalist, began the first botanical excursions in Nepal in 1802–1803, followed by Nathaniel Wallich (1820–1821), and many more foreign and Nepalese explorered with the purpose of collecting plants **(**Rajbhandari, 2016). Over 218 years of exploration, 1600 new blooming plants species from Nepal have been found (Rajbhandari *et al*., 2019). Nearly majority of Nepal's botanically researched regions are chosen by foreign botanists rather than native Nepalese and the studies are concentrated on high mountains and conservation regions rather than mid-hills and plain areas. Therefore, several regions of Nepal may have botanically unexplored or little explored, especially in the lowlands of western Nepal. This research site, which has little known botanical information, may contain a collection of mid-hill and Churia Hill species as well as a meeting point for species from the eastern and western Himalaya. Similarly, the botanical study of any unexplored area is helpful for the government, planners, biologists, and locals in any location from a taxonomical and conservation aspect.

However, it is not systematic. Plant life form is frequently used to show relationship with environmental factors in ecology (Adamson, 1939). Other many botanists divided the plants into different classes on the basis of different criteria. Herb, shrub, tree, climber, liana, and other life forms are often used, but it is unknown who first coined these terms. On the basis of the situation of the growth point during the unsuitable periods, Raunkiaer (1934) divided plants into the following classes: Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes and Therophytes. The plants found in this work is divided on the basis of this system

Understanding patterns of distribution and the variables that influence them is crucial for effective biodiversity protection and sustainable use. The demand for such knowledge is expanding as biodiversity adjusts to climate change's ongoing consequences. (Swenson *et al*., 2012). This section is aimed to find out the vascular plant assortment on the basis of taxa, life-forms and forest types and compare the biodiversity indices and IVI of plant life forms.

2. 2 Literature Review

2.2.1 Plant diversity studies outside from Nepal

In 18th and 19th centuries, Europeans started to explore with the aim of discovering new countries or places outside of Europe, whether as explorers, merchants, or missionaries. They brought back plants they had collected from various locations throughout the world to store in gardens and herbariums (Bleichmar, 2012). Early plant collectors made advantage of the opportunities to learn about, comprehend, and assimilate local cultures as well as supply the great European gardens with a wide variety of plants (Edwards, 2021). Between the 18th and the early 20th centuries, botanists at gardens in Kew, Edinburgh, Madrid, Berlin, St. Petersburg, Singapore, and Bogor, at natural history museums in Paris, London, Leiden, and later Washington, as well as universities in Uppsala, Oxford, and Harvard, described new species of plants at a fast pace, particularly from tropical regions of the world (Kress , 2005).

In 1839–1843, Sir Joseph Dalton Hooker traveled from England to the South Pole of the Antarctic through several nations that were close to the Pacific Ocean and gathered numerous plants for the Edenberg University Garden. British botanist George Forrest narrowly intered and travelled from Tibet through upper Burma, eastern Tibet, and Sichuan province in 1904 and gathered over 31,000 specimens from China, discovered more than 1,200 new plant species, and had more than 30 taxa named in his honor (McLean, 2004). British botanist Ernest Henry Wilson travelled in East Asia throughout Japan, Taiwan, and Korea from 1917 to 1919 and collected germplasm from cultivated and the wild. He took over 700 photos of the flora and over 30,000 dried specimens from over 3000 distinct species (HL, 2022)..

The first Dutch invaders and plant explorers explored the rich plant life of the Indian Subcontinent in the 16th and 17th centuries. Then, Portuguese and Europeans, particularly William Roxburgh, Nathaniel Wallich, William Griffith, Sir J.D. Hooker, and others followed. The works and collections of several herbaria and libraries exist, including Kew in the United Kingdom and several in India (Sikarwar, 2020).

After 1950, numerous scientists from various nations began exploring and studying plants without the involvement of the Europeans. Lillo *et al*. (2019) recorded 432 native species that belonged to 87 families, 203 genera, and 40 endemic plants Dinagat Island, Philippines. In the Himalayas of Kashmir, Gulzar *et al.* (2022) investigated the diversity of two treeline ecotone sites by field sampling using five 20-m^2 plots and identified 97 plant species from 33 families, noting significant differences in species distribution and composition throughout the treeline ecotone. Perennial herbs were the predominant species reported. Thi s study offers vital baseline information that will make it easier to assess and monitor the Himalayan treelines in an era of global warming.

Botanists began to link ecological considerations to plant dispersion at the same time as plant exploration. Danin & Orshan (1990) studied the dissemination of Raunkiaer life forms in 27 geomorphological zones in Isarael and Phanerrophytes and Chamaephytes were significantly more common in regions with extremely low mean annual rainfall (decreasing up to 150 mm and 400 mm), and they practically remain the same at higher rainfall quantities. Geophytes and Hemicryptophytes are more prevalent along the gradient of rainfall. Therophytes prefer rainfall 200 and 500 mm per year. The dispersal of living forms is fewer noticeably connected with mean temperature, despite Hemicryptophytes and Geophytes having an adverse relationship with mean annual temperature and mean annual minimum temperature.

Pielech (2021) compared the species abundance in riparian forests with other plantation types in the same location across numerous watersheds in the Sudetes (Poland, Central Europe). He examined the result of geography on species diversity and the latitudinal species richness pattern on both the local and regional scales. Compared to beech and rand ravine forests, riparian forests contain a substantially higher level of alpha diversity. All forest types contained a comparable proportion of rare species, and in riparian forests, their eight distinct groups could be differentiated and reflected the diversity and dynamism of the riparian zone. He suggested a gaussin curve of gamma diversity against the longitudinal ascent.

By utilizing diversity indices, botanists have begun to determine the diversity of the plant kingdom. Sharashy (2022) compared the plant species diversity on Egypt's Coastal Rocky Ridges Habitats. The results showed that the Shannon index (H') value was 2.058 and 2.322, the Simpson index (D) value was 0.85 and 0.92, the Evenness index (E) value was 0.89 and 0.96, and the Actual Number of Species value was 6.66, 7.83, and 12.5, separately in Ras El-Hekma region, and Omayed protectorate . The findings exposed that when compared to the Ras El-Hekma region, the greatest levels were seen in the Omayed protectorate village. Moderate diversity ($2 \geq H' \leq 3$) seen in the results of the two communities. Both communities are stable, as measured by the evenness index, which is 0.75 >E 1. Based on the values of effective number species, Shannon, Simpson and Evenness indices, the Omayed had high level in environmental wellness and biodiversity.

Tian *et al.* (2007) analysed the plant specimens collected from Three Gorges region, China. Comparisons of Shannon-Wiener index and Pielou evenness index outcomes presented that the the shrub covers more area, which was tracked by grassland, and tree covers was the lowest. The four shrubs *Vitex negundo* var. *cannabifolia, Rhus chinensis, Cotinus coggygria* var. *cinerea* and *Coriaria sinica* showed high Shannon diversity index 1.791, 3.427, 2.949 and 1.718, respectively. There were 4 grassland societies in higher ltitude (*Arthraxon hispidus, Dicranopteris dichotoma, Miscanthus floridulus* and *Imperata cylindrica* var. *major*) exposed greater richness (1.70, 1.36, 1.15 and 1.02, correspondingly).

Quantitative methods are frequently used in botanical studies and key traits are frequency, variety, cover, biomass, leaf size, abundance, dominance, IVI and others. Korhonen *et al.* (2006) assessed the canopy cover in 19 Scots pine-dominant plots by the line intersect sampling, Cajanus tube, a improved spherical densiometer, digital pictures, and ocular estimates. Multiple comparisons and the nonparametric Kruskall-Wallis analysis of variance were employed to assess the statistical implication of the variations between the techniques. The estimates generated using labor-intensive methods (like line intersect sampling and the Cajanus tube) are often more accurate and unbiased, but those generated using quick methods (such digital images and ocular estimating) have bigger variances and may also be considerably biase.

The flora of the Naran valley in Pakistan was sampled by Khan *et al.* (2012) and was divided into three categories: trees (height > 5 m), shrubs (1–5 m), and herbs (height < 1 m). All vascular plants' existence or absence was noted on pre-made data sheets (1, 0 data). In order to estimate the coverage of herbaceous vegetation visually using the

Daubenmire and Braun Blanquet methods, the perimeter of trees at breast height were measured using a tape measure. The diversity indices of plant communities and habitat categories were calculated using data analysis. The biodiversity of plants decreased with elevation, according to the results for five plant groups and habitat types. The Shannon Diversity Index ranges from 3.3 to 4. The communities/habitats on north-facing slopes at medium elevations displayed the greatest values for all of these diversity indices as compared to the southern slopes. The high moisture present in the soil supports high biodiversity in return.

Tolangara *et al.* (2019) used 20 x 20 m plots for trees to evaluate the structure and important value index of each variety of tree species used as food in Bacan Island, Australia. *Drancontomelon dao* has the greatest IVI (52.78%). *Duabanga moluccana, Canarium casferum, Theobroma cacao, Bacacaurea angulata, Myristica fatua,* and *M. speciosa* all reported medium IVI (31.47-44.42%). *Mangifera indica* had the lowermost IVI (29.52%) of all the plants that could potentially provide nutrition for wild animals.

In the Nanda Devi Biosphere Reserve, (2050 to 3800 m above sea leve), Rawat *et al.* (2021) showed a quantitative study of the plant species present in the Lata-Tolma-Phagti (LTP) and Pindari-Sunderdhunga-Kafni (PSK) area, Garhwal region. Overall, 4278 unique trees from 42 households were documented at the PSK area, and 6436 trees from 25 families were recorded at the LTP site. In the PSK site, the density significantly decreased at a proportion of 319–355 ind/ ha per 100 m altitude ($P < 0.01$), but in the LTP site, the density increased per100 m elevation at a speed of 53–56 ind/ha. The proportion of change in species abundance and density100 m contour elevation over elevational gradients is highlighted in the study.

2.2.2 Plant diversity in Nepal

British scientists first entered in east Nepal from India, and carried out a plant survey of eastern Nepal and India. According to previous botanical studies, the majority of study is centered on eastern and central Nepal rather than western Nepal. Stainton (1972), Dobremez & Shrestha (1978), and Shrestha (1982) conducted major investigations in western Nepal, focusing on the north-west or Karnali area **(**Uddin *et. al.*, 2015**).** The dispersal of flora in the trans-Himalayan region is mainly controlled by variations in elevation and monsoon, as well as terrain, soil, and other biotic variables (Stainton, 1972; Dobremez, 1976).

Foreign researchers' studies in Nepal aided in our comprehension of the country's biodiversity. In According to the study of Vetaas & Grytness (2002) in case of the Nepal Himalayas, endemic species normally rise proportionately with elevation, and above roughly 4000 m, endemic species discovered declined owing to a rapid fall in species richness.

Numerous scientists from Nepal have independently or together worked on Nepal's biodiversity. Basnet (2013) collected nearby 224 phanerogam species belonging to 67 families and 173 genera from the Rara Lake and adjoining area, west Nepal. Among them, Asteraceae was found the major family (21 species and 17 genera) tracked by Rosaceae (19 species and 10 genera). Similarly, Kunwar et al. (2019) found from an ethnobotanical research of the Kailash Sacred Landscape in Nepal that plant use value was impacted by environmental (Shannon diversity, species richness) and cultural variables (desire for certain products and recognition) and different at the level of use category. Ghimire *et al.* (2021) identified 642 plant species belonging to 42 families and 231 genera of gymnosperms and few angiosperms (Ephedraceae – Buxaceae) found in Kailash Sacred Landscape, Far west, Nepal.

Shrestha *et al.* (2005) studied the trans-Himalayan North West area of Nepal (from Jomsom, Mustang to Kagmara, Dolpa) and described six types of vegetation patterns: Alpine zone, alpine shrubs (dry alpine shrub and moist alpine shrubs), alpine meadows, nival formation and agricultural borders.

Sah *et al*. (2001) studied about the floristic assortment and use of plants in Ghodaghodi lake area, far western Nepal and listed 401 species from 84 families**.** Rai *et al.* (2016) studied the environmental situations constraining species abundance and alignment patterns in. two valleys from Manaslu Conservation Area (MCA) and two valleys from Sagarmatha region. They collected 790 vascular species related to 114 families within 148 plots of elevation range 2,200 - 3,800 m above sea level and Asteraceae (84 spp.) was found as the largest family.

Many plants have been collected by the scientists who work for the Department of Plant Resources from various locations around Nepal. The finding of these works are being published in books and the Journal of Plant Resources. These works show the relation of the elevation and enumeration of plants.

2.2.3 Plants studies in Arghakhanchi and its adjoining areas

According to botanical research, Lumbini province of Nepal is a less visited region. There was no known record of extensive national or international exploration teams exploring this region, except from a few individual researchers. Arghakhanchi district is a part of this province.

Enumeration and ethnobotany are the main focuses of the study projects undertaken about the plants of the Arghakhanchi district and its surrounding areas. Panthi & Chaudhary (2002) listed a total of 501 angiosperm species belonging to 113 families and 373 genera in Arghakhanchi district in his PhD thesis on ethnobotanical study. Similarly, Panthi & Singh (2013) listed 31 plant species of 24 families that were utilized to treat dermatological and cosmetic diseases in this district. Dhakal *et al*. (2021) lited discovered 103 plant species from 56 families that were utilized to cure 21 domestic animal illnesses in Chhatradev, Arghakhanchi.

Acharya (2012) reported 144 genera and 161 plant species that were utilized by the Magar population in Badagaun, Resunga, and Gulmi. The bulk of them are herbs, and they are mostly used to treat gastrointestinal illnesses. Sharma *et al.* (2015) measured the Importance value index, Shannon-Weiner index, evenness, and carbon stock of *Rhododendron* and oak forest in Resunga sacred forest (2100-2450 m). He found that the Rhododendron forest was more diversified (H = 1.0) than the oak forest (H = 0.9), while the oak forest had more equally distributed tree species (0.87) than the *Rhododendron* forest (0.77). Rhododendron forest has a smaller vegetative carbon stock (101.8 ton/ha) than oak forest (153.8 ton/ha).

Jnawali & Neupane (2021) studied 185 species from 154 genera and 74 families in Gulmi's Madane Protected Forest. The dominating families were Asteraceae, Rosaceae, Poaceae, and Lamiaceae. Similarly, highly priority plants such as *Swertia chirayita, Paris polyphylla, Dioscorea deltoidea* and *Tinospora sinensis* were reported, while an indigenous species, *Hypericum cordifolium* (Hyperiaceae), was recorded for the first time from this forest.

Thakuri *et al.* (2018) conducted bird surveys in the Madane Protected Forest in Gulmi. Cheer Pheasant, Asian Woollyneck, Egyptian Vulture, Red-headed Vulture, Steppe Eagle, Bearded Vulture, and Himalayan Griffon were universally vulnerable species among the 184 bird species reported.

Aside from a few individual researchers in this area, no national or international exploration teams have been conducted for plant excursion to far. The conducted studies are solely concerned with counting plants or doing ethnobotanical research. This demonstrates that less studies of biodiversity have been conducted using biodiversity indices or in-depth quantitative efforts in this field.

2.3 Material and Methods

2.3.1. Primary data collection

2.3.1.1 Pilot field visit and sampling location selection

The sampling locations were selected on the basis of hills extended from low to high elevation. To cover the entire area of study site, 9 locations (hills) were selected at two landscapes (Narapani-Masina and Resunga -Malarani landscape). Out of these locations, 4 remain at Narapani-Masina landscape namely: Pattharkot (27.7583°N, 83.05327°E, 220 m) - Narapani (27.90623°N, 83.14557°E, 1810 m), Jhimruk river-Sengleng (27.92424°N, 83.05196°E, 483 m to 27.09742°N, 83.0859°E, 2033 m) at south and south -west aspect and Rithekhola-Masina (27.95438°N, 83.16682°E, 822 m to 27.91272°N, 83.1149°E, 2149 m), Durghaphat-Kalikathi (27.92304°N, 83.26417°E, 725 m to 27.86299°N, 83.2196°E, 1837 m) at north site.

Similarly, 5 locations which were present at Resunga-Malarani landscape, namely, Chaldi-Panaha (28.06402°N, 83.1067°E, 788 m) to Resunga tower (28.0659°N, 83.26742°E, 2288 m), Kafalneti-Gokhunga (28.123889°N, 82.9957°E, 1043 m to 28.09648°N, 83.01387°E, 2048 m) at north aspect. The other locations present at south aspect in this landscapes are: Samne khola, Dhakabang (28.04645°N, 82.98677°E, 661 m) to Gokhunga (28.09648°N, 83.01387°E, 2048 m), Laddakh, Sandhikhark to Malarani (27.985°N, 83.12873°E, 981 m to 28.06445°N, 83.09328°E, 2124 m) and Diverna-Jalkanda (27.996817°N, 83.176578°E, 848 m to 28.03037°N, 83.16935°E, 1920 m).

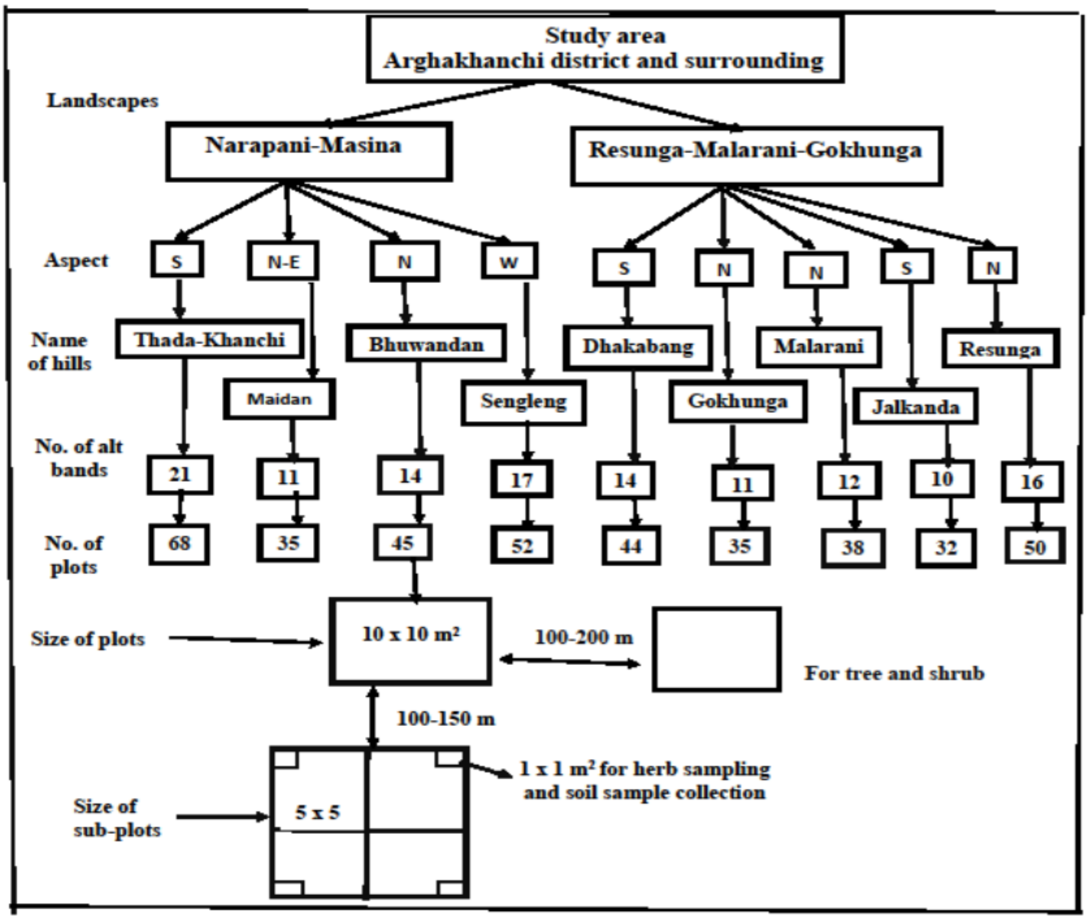


Figure 4: Sampling strategy for primary data collection

2.3.1.2 Elevational division and Sampling sites

The study site was visited briefly about 6 months prior to start the field work. Map of the study area, interaction with locals and formal permission processes to authorities was conducted at the beginning. After formal acceptance by local authority, field work was started.

The sampling process was started from the lowest elevation of Arghakhanchi district-Pattharkot (Darbardanda, 200 m from south boarder) and continued up to the highest (2288 m) peak Resunga of Resung- Malarani landscape. The field excursion and sampling process was done at first on October-November 2018. Same process was repeated on October-November of 2019 at sampled sites. I traveled to the same sampling locations in March and April 2019 with my field assistants to collect plants throughout the spring season.

There was not equal elevation range in each study locations (or hills). The elevation range of each location was divided by 100 m band: Thada-khanchi (Patharkot-

Narapani) 220-2149 m into 21 bands, Maidan (Durgaphat-Kalikathi) 725-1830 m into 11 bands, Bhuwandanda (Rithekhola-Masina) 830-2149 m into 13 bands, Sengleng (Jhimruk-Sengleng) 483-2033 m into 16 bands, Dhakabang (Jhimruk-Gokhunga) 610-2024 m into 14 bands, Kafalneti-Gokhunga: 1080-2024 m into 10 bands, Sandhikharka-Malarani: 950-2124 m into 12 bands, Diverana (Jarekhola-Jalkanda) 953-1920 m into bands and Resunga (Chhaldi-Resunga top) 788-2288 m into 16 bands (Figure 4).

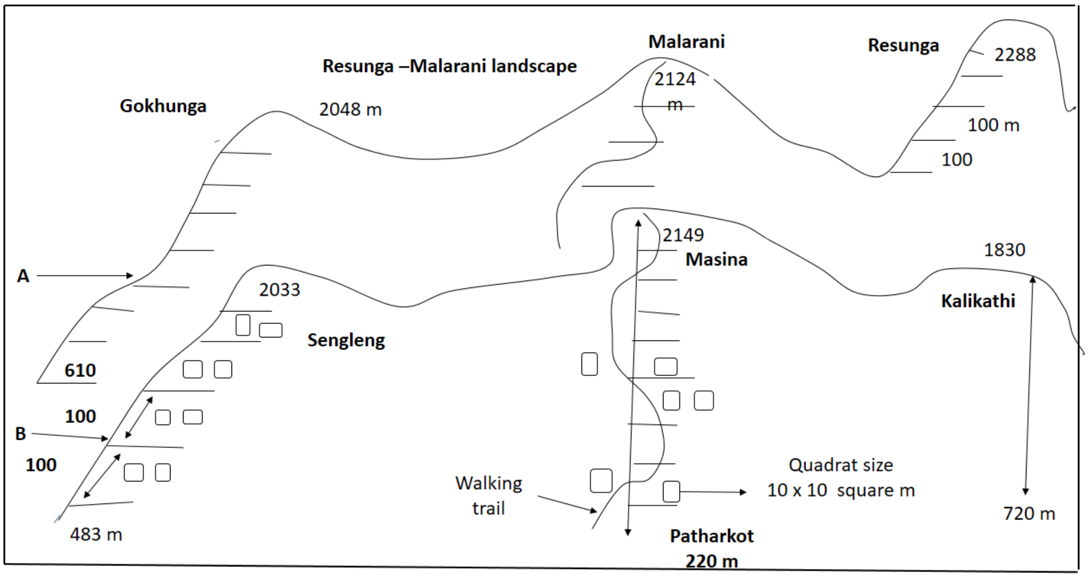


Figure 5: Elevational band division and quadrat sampling in two landscapes. A. Narapani-Masina, & B. Resunga-Malarani (View from south aspect)

2.3.1.3 Determination of quadrat size and plant sample collection

The following techniques were used to determine the qualitative and measureable aspects of the vascular species in the Arghakhanchi district and its neighboring areas

The geographical and ecological survey of study area was observed through naked eye. The requisite size of quadrat for tree sampling was fixed by species area curve method in the forest of Darbardanda, Sitganga Municipality. The sampling was started by 2x2 m^2 area and it was increased by 2 meter in both axes up to 16x 16 m^2. This method showed the requisite size of quadrat for tree sampling was 10 x 10 m^2 because same number of species was present above than this size. Quadrat of same size was also applied in other sites of study area.

Two sites selected in each 100 m elevation band present on either sides of walking trail in each location. Minimum two 10 x 10 square m sized quadrats used for collection of tree species each site. In some sites, having different vegetations, more than 2 quadrats were also used, Altogether 398 quadrats used in 181 sites (**Annex 1**) in entire study area (**Figure 4 & 5**). This sized quadrat was divided into equal 4 parts and 2 small quadrats of sized 5 x 5 m^2 of same large quadrats were applied for shrub and climber species sampling. Similarly, 1 x 1 m^2 sized quadrat were used to collect the small plant species from 4 corners of quadrat (10x 10 m^2) (**Figure 4**).

2-3 individual plants of each species collected for herbarium preparation. Tag numbers were attached in each plant specimens. The elevation of site, other ecological and morphological characters also noted in field notes. The photographs of each plants were taken for further study.

2.3.1.4 Plant species identification

By use of dried specimens, their proper herbarium was prepared by following standard procedure as prescribed Siwakoti *et al.* (2015).

Most of the tree, shrub and some of the other plant species were identified with the assistance of local people and field assistants. Most of the collected plant species were identified by comparing with already identified plant herbarium present in National herbarium and plant laboratory (KATH), Godavari and Central herbarium (TUCH), Tribhuvan University with the co-operation of botanists servicing in these laboratories. The following literature were applied for plant identification: Flora of Bhutan (Grierson & Long, 1983, 1984, 1987, 1991, 1999, 2001., Noltie, 1994 & 2000), Fern and fern allies of Nepal (Fraser-Jenkins *et al.,* 2015; Fraser-Jenkins & Kandel, 2019; Kandel & Fraser-Jenkins, 2020), Flora of Nepal, volume 3 (Eds. Watson *et al*., 2011) 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). The identified plant specimens were deposited in TUCH herbarium, Central Department of Botany, Tribhuvan University, Kirtipur, Nepal.

2.3.1.5 Plant life form categorization

Different terminologies (herb, shrub, tree, climber, liana, creeper, etc.) are widely used to describe the many growth forms or life forms of vascular plant species. There was insufficient data about actual persons who used these categories for the first time. However, Raunkiaer (1934) divided plants into the following kinds of living forms according to where their growth points are located during adverse times:

a) Phanerophytes: growth point in critical season more than 50 cm above ground level, often on stems (e.g. trees, bushes, lianas).
b) Chamaephytes: growing point in critical periods less than 50 cm above ground level (e.g. many perennial herbaceous plants).
c) Hemicryptophytes: growth point in critical time above or just below the soil
d) Geophytes or Cryptophytes: growth point remains below ground in unfavorable season
e) Therophytes: as reproduced by seed (annual plants).

Thus, the Raunkiaer's life form classification led to the following categories for the detected vascular plants: Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes and Therophytes.

2.3.1.6 Forest type categorization

The most of the plots were laid in forest and few laid in grasslands. The forest area was cover up of trees and bush species. On the basis of dominant species of trees, shrub and others species present in the plots, vegetation of study area was divided into several forest types, in accordance with Stainton's description of Nepal's forest (1972).

2.3.2 Secondary source

The secondary data of vascular plant species present in Arghakhanchi district was composed from already published journal articles (Panthi & Chaudhary, 2002; Acharya, 2012; Panthi & Singh, 2013; Acharya *et al*., 2015; Jnawali & Neupane, 2021), PhD thesis (Panthi, 2005), books (Fraser-Jenkins *et al.*, 2015; Fraser-Jenkins & Kandel, 2019).

2.3.3 Data analysis

The vascular plant diversity data was analyzed by use of Excel program.

2.3.3.1 Diversity indices calculation

Species diversity present in each quadrat or community is also called alpha diversity. The species richness was determined by counting the species number. The 100 m contour elevation consist of more than one quadrats in this study. So, total species present in all quadrats of each 100 contour elevation is considered as alpha diversity, which is used to show the elevational pattern of species.

These indices are statistical representations of biodiversity in different aspects. The popular diversity indices: Shannon diversity index (Shannon-Wiener Index), Simpson index and Pielou evenness were used to estimate the diversity indices of alpha diversity (Parchizadeh, 2018).).

I) Shannon-Winner Index

It is determined by the following formula:

Shannon Index (H) = $-\sum Pi * \sum In\ P_i$

Where, Pi is the fraction (n/N) of individuals of one specific species found (n) divided by the total number of individuals found (N),

In is the natural log, Σ is the totality of the calculations, and s is the species number.

ii) Pielou's measure of species evenness (Shannon evenness idex)

It is estimated by use of this formula:

$J = H'/\ln(S)$

Where,

J- Pielou's measure of species evenness
H' - Shannon Weiner diversity and
S - Total number of species in a sample, across all samples in dataset.

iii) Simpson diversity index

The Simpson diversity index was determined by the following formula:

Siinpson diversity index

$$\mathbf{D = 1 - \frac{\sum n(n-1)}{\sum N(N-1)}}$$

n=number of individuals of each species

N=total number of individuals of all species

2.3.3.2. Vegetation analysis

Vegetation analysis is the way to study species arrangement and structure of plant community. The vegetation can be studied in two types of characters: qualitative characters and quantitative characters. On the basis of elevational range (200-2300 m), the entire study area can be categorized into 3 ecological zones: tropical (below 1000 m), Sub-tropical (1000-2000 m) and temperate (above 2000 m). The data obtained from quadrats of 3 ecological zones were analysed separately. The density, frequency, coverage or abundance and IVI are frequently used as quantitative parameters. From the field data, density, frequency, basal area and the importance value index (IVI) of each plant species were calculated using methods of Zobel *et al.* (1987).

2.3.3.2. a Density

Density of any species means individuals of particular species present in unit area. The subsequent formula was applied to calculate the density and relative density of species:

$$\text{Density (D)}\left(\frac{\text{ind}}{\text{ha}}\right)=\frac{\text{Total number of individual of a species present in all quadrats}}{\text{Number of quadrats X Size of quadrat (m)}}\text{X }10000$$

$$\text{Relative density (\%)}=\frac{\text{Density of individual species}}{\text{Density of all studied species}}\text{ X }100$$

2.3.3.2. b Frequency

Frequncy of plant species is the sum of times it appears in a certain number of quadrats. A Frequency Index is a common name for frequency, which is typically given as a percentage. The frequency or abundance and relative frequency were calculated by use of the following formulae:

$$\text{Frequency (\%)}=\frac{\text{Quadrat number in which individual species occured}}{\text{Total number of quadrat studied}}\text{X }100$$

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

2.3.3.2. c Coverage or dominance

The coverage is the area covered by plant parts. The canopy coverage of small plants (herbs, climber, and shrubs) is estimated by visual observation through naked eye.

The mid value of coverage range of individual species was noted by following of 6 cover classes (according to Daubenmire, 1959).

The coverage of trees cannot be estimated by canopy coverage method. So, coverage in case of tree can be estimated by measuring the perimeter at breast height (DBH). Plant species having DBH (diameter at breast height) more than 10 cm were measured as tree species (Singh & Singh 1981).

The perimeter at DBH of all individuals of particular trees species present in each quadrat were noted. Basal area (BA) of a tree was estimated from the diameter. The diameter of tree was calculated from the perimeter. The following formula was used to measure the basal area of tree:

$$\text{Basal area (BA)(per ha)} = \frac{(\text{Perimeter})2}{4\pi \text{ X Area of quadrat}} X\ 10000$$

The relative coverage of each species was estimated by use of the below mentioned formula-

$$\text{Relative coverage(RC or RBA) (\%)} = \frac{\text{Coverage of individual species}}{\text{Coverage value of all studied species}} \text{X } 100$$

2.3.3.2. d Important Value Index (IVI)

The IVI is the aggregate value of Relative density, Relative frequency and Relative coverage. The IVI of separate species was estimated by the following formula:

Important Value Index (IVI) = RD+ RF+ RC

2.4 Results

2.4.1 Biodiversity measurements

2.4.1.1 Species richness on the basis of taxa

The empirical total vascular plant species present in Arghakhanchi district and its adjoining area - Resunga peak showed that this area was rich in plant diversity. Altogether 606 vascular species related to 123 families and 418 genera were reported in research site. On the basis of plant taxa- Dicots, Monocots, Pteridophytes and Gymnosperms were found in decreasing order of species (**Table 1**).

Table 1: The vascular plant diversity of Arghakhanchi district and adjoining area (primary source)

S.N.	**Taxa**	**Richness**			
		Families	**Genera**	**Species**	**Percentage**
1	Dicots	87	305	414	68.32%
2	Monocots	16	75	105	17.33%
3	Gymnosperms	2	3	5	0.83%
4	Pteridophytes	18	35	82	13.53%
Total		**123**	**418**	**606**	

Among the dicot taxon, Leguminosae (Fabaceae) obtained the largest family with 32 genera and 50 species (**Figure 6 A**). It was followed by Poaceae, Asteraceae and Lamiaceae families. Among the genera of dicot, *Ficus* and *Thelypteris* occupied the largest genera (**Figure 6 B**).

Any species, or taxonomic unit, whose distribution is limited to a single, constrained geographic area is considered an endemic taxonomic unit or endemic species. There was not found any endemic species in the study area.

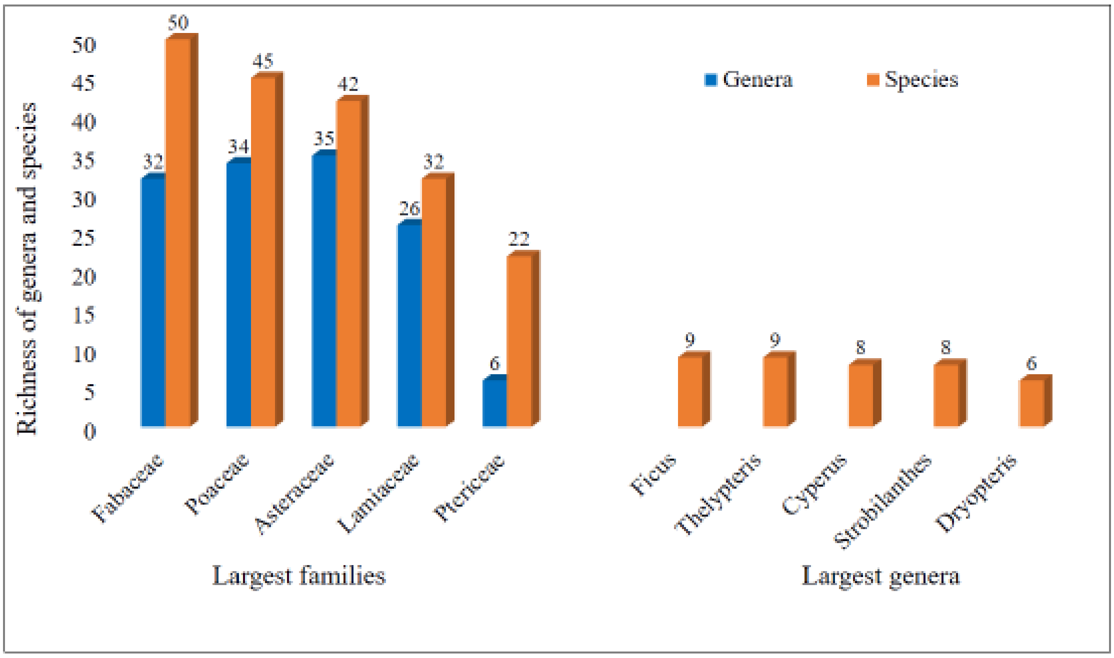


Figure 6: The largest families and genera of vascular taxa

2.4.1.2 Life-form diversity

One of the most famous physiognomic techniques of vegetation description is the life-form method of Raunkaier (1934). Based on the placement of a plant's bud during adverse seasons, he divided the plants into five life-form classes and later, de Mera *et al*. (1999) added some of the classes in Raunkier's life form classification.

Table 2: The life - form species diversity according to Raunkiaer's classification (1934).

S. N.	Life form	Family	Genera	Species	Percentage	Mean alpha diversity
1	Phanerophytes	74	203	265	43.73	73.14
2	Chamaephytes	14	29	37	6.11	10.5
3	Hemicryptophytes	41	141	158	26.07	30.05
4	Geophytes	19	40	57	9.41	14.17
5	Therophytes	19	65	89	14.69	26.36
	Total vascular plants	125	402	606	-	158.2

The five basic life forms according to Raunkiær (Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes and Therophytes) are used for analysis in this research.

Phanerophytes obtained the highest value in all three biodiversity measurements. It obtained the highest gamma diversity - 265 species (related to 74 families and 203 genera) or 43.23% in overall and it was followed by Hemicryptophytes (27.07%). On the other side, Chamaephytes (37 species) obtained the least gamma diversity (**Table 2**). Similarly, Phanerophytes obtained the highest mean alpha diversity (73.14 species) per 100 m contour elevation among the life form classes (**Table 2**).

2.4.1.3 Forest type and species richness

On the basis of woody species, the forest is broadly divided into 5 types: mixed Sal forest (main species is *Shorea robusta*), mixed conifer forest (main species are: *Schima wallichii, Castanopsis indica),* Mixed Pine forest *(*Main species *Pinus* *roxburghii, Shorea robusta, Castanopsis indica*), Quercus-Rhododendron forest (main species: *Quercus lanata*, *Q. semecarpifolia*, *Rhododendron arboreum* and *Alnus nepalensis*) and riverine grassland. The mixed Pine forest and grassland obtained the highest (390) and the lowest (165) species richness (**Annex 3**). The species richness of different forest types was tested by Tukey post hoc test. The result showed that richness of grassland and Quercus forest were found significantly different than species richness of other forest types (**Figure 7 A**). The Sal (*Shorea)* forest and mixed Pine forest were found rich in plant diversity than other forest types.

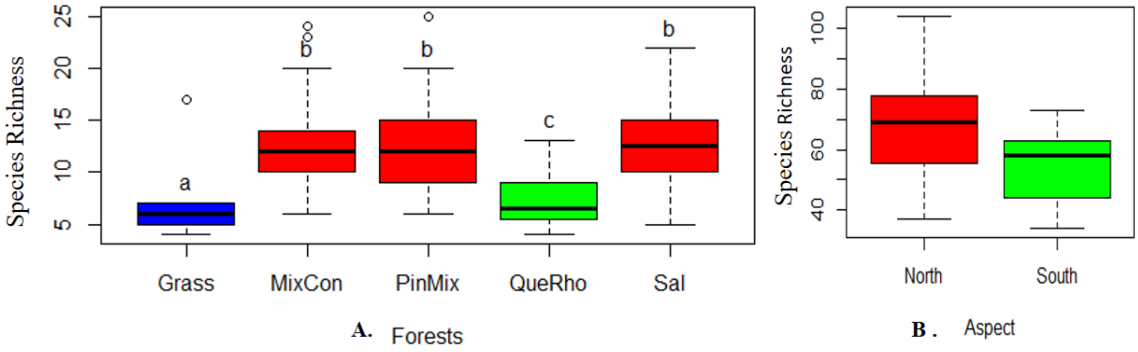


Figure 7: Result of Tukey post hoc test of species richness relationship on the basis of: A. Forest types, and B. Aspects (North and South, p =0.0262)

The elevation range of two aspects (south and north) was not similar. Number of sampled quadrats were not also same. So, plants present in quadrats in equal elevation bands (700-2100 m) in both aspects applied for Anova test. The result presented that there was substantial ($p < 0.05$) difference in species richness of forest of north and south aspect of landscapes (**Figure 7 B**).

2.4.2 Diversity indices

Diversity indices offer crucial details on the rarity and dominance of species in a group. To estimate the indices of diversity: Shannon-Wiener index, Simpson index, and Pielou' evenness were utilized. The Phanerophytes obtained the higest value of the Shannon index (2.33 ± 0.49), Simpson index (0.85 ± 0.08) and Pielou’s evenness (0.84 ± 0.09) in vascular plant species of entire study area. It was followed by Hemicryptophyre in all three indices (**Table 3**). The Chamaephytes occupied the least value of the Shanon and Simpson idices, but the Geophytes showed the least value of Pielou’s evenness. The total species showed the higher value all diversity indices incomparison to individual life form (**Table 3**).

Table 3: The biodiversity indices (Shannon-Wiener index, Simpson index and Pielou's evenness) of plant life forms

S.N	Plant Life forms	Diversity indices values		
		Shannon-Wiener index	**Simpson index**	**Shannon evenness index (Pielou's evenness)**
1.	Phanerophytes	2.33 ± 0.49	0.85 ± 0.08	0.84 ± 0.09
2.	Chamaephytes	0.53 ± 0.49	0.31 ± 0.27	0.77 ± 0.16
3.	Hemicryptophytes	1.36 ± 0.49	0.65 ± 0.18	0.78 ± 0.14
4.	Geophytes	0.75 ± 0.35	0.62 ± 0.23	0.62 ± 0.23
5	Therophytes	1.22 ± 0.55	0.58 ± 0.21	0.74 ± 0.17
	Total vascular plants	2.75 ± 0.42	0.89 ± 0.07	0.79 ± 0.08

2.4.3 Vegetation analysis

The quantitative parameters: density, frequency, coverage and IVI of each life forms species found in three ecologicall regions were estimated for vegetative analysis.

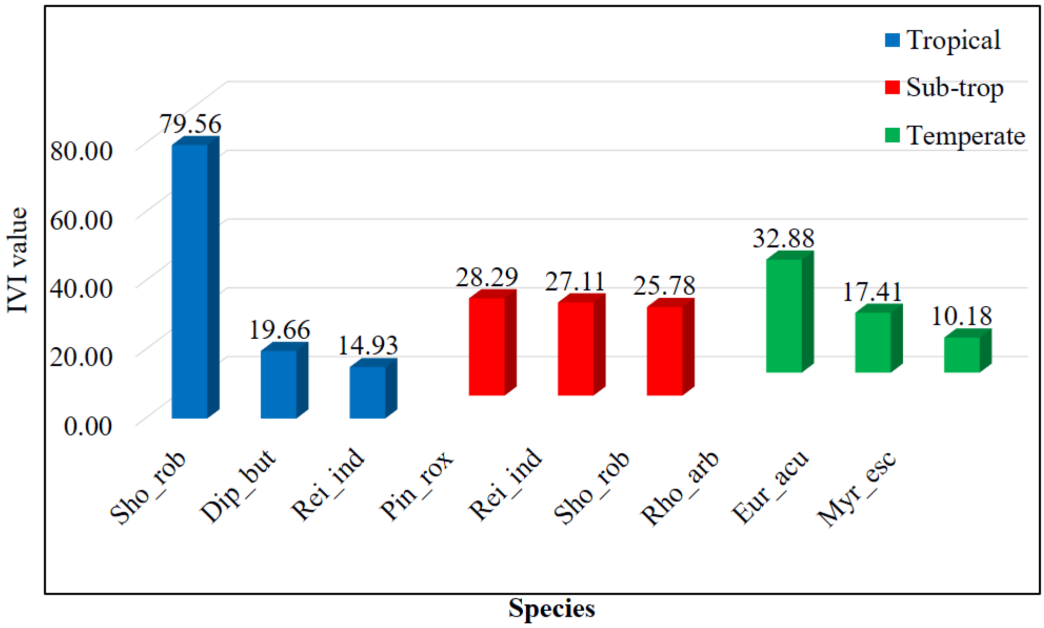


Figure 8: The Phanerophyte species present in different ecological zones having the highest IVI values.

The three Phanerophyte species occupied the highest IVI value in three ecological regions. *Shrea robusta, Pinus roxburghii* and *Rhododendron arboreum* obtained the IVI value 79.56, 28.29 and 32.88 respectively, which were the highest IVI occuring species in tropical zone, sub-tropical region and temperate regions (**Figure 8** and **Annex 4**). They were followed by *Diploknema butyracea*, *Reinwardtia indica* and *Eurya acuminata* in three ecological zones respectively.

Among the Chamaephyte species: *Rumex hastatus* had the highest IVI value: 33.66 and 92.50 in sub-tropical and temperate regions respectively but *Duhaldea cappa* (Syn. *Inula cappa*) obtained the highest IVI value in tropical region (**Figure 9** and **Annex 4**). They were followed by *Sida cordata, D. cappa*, and *Dipsacus inermis* in tropical, sub-topical and temperate region respectively.

The *Capillipedium assimile* showed the highest but decreasing trend of IVI value: 138.33, 119.10 and 92.05 in tropical, sub-tropical and temperate regions respectively (**Figure 10** and **Annex 4**). Simlarly, they were followed by *Brachiaria villosa, Oxalis corniculata* and *Geranium nepalense* in three ecological regions respectively.

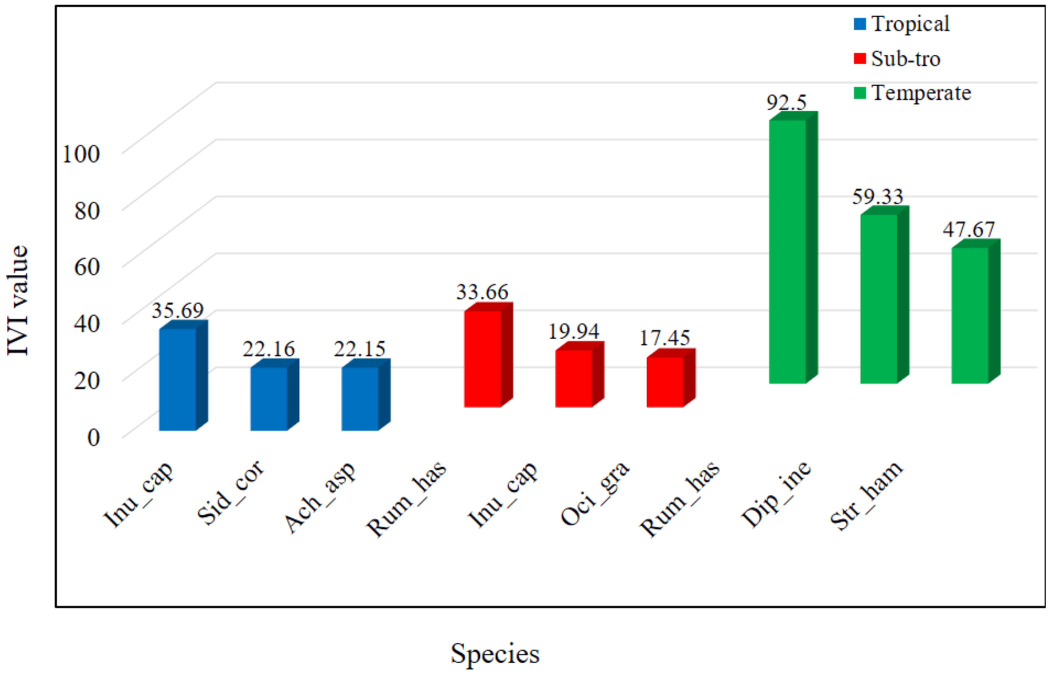


Figure 9: The Chamaephyte species present in diffeent ecological zones having the highest IVI values.

Among the species present under Hemicryptophytes, *Saccharum spontaneum, Cynodon dactylon* and *Erioscirpus comosus* obtained the highest IVI values in tropical, sub-tropical and temperate regions respectively (**Figure 10** and **Annex 4)**.

The *Imperata cylindrica* obtained the second highest value in tropical and Sub-tropical regions but *Drymaria diandra* second highest position in Hemicryptophytes.

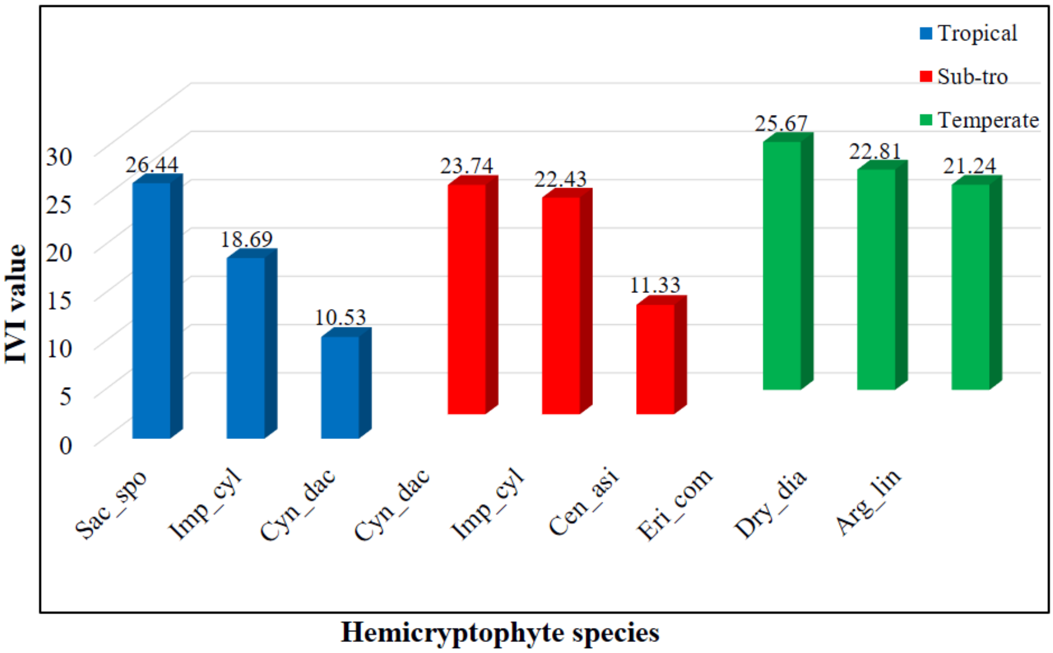


Figure 10: The Hemicryptophyte species present in different ecological zones with the highest IVI values.

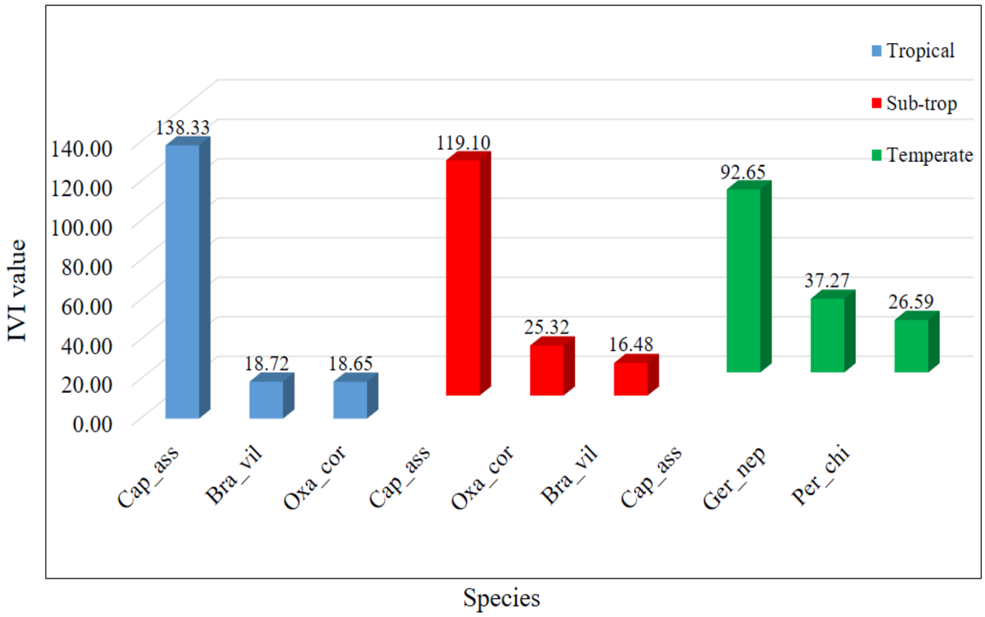


Figure 11: The Geophyte species present in different ecological zones having the highest IVI values.

Among the Therophytes species, *Ageratina adenophora* and *Ageratum conyzoides* got the first and second position in all three ecological regions. *Ageratum conyzoides* got

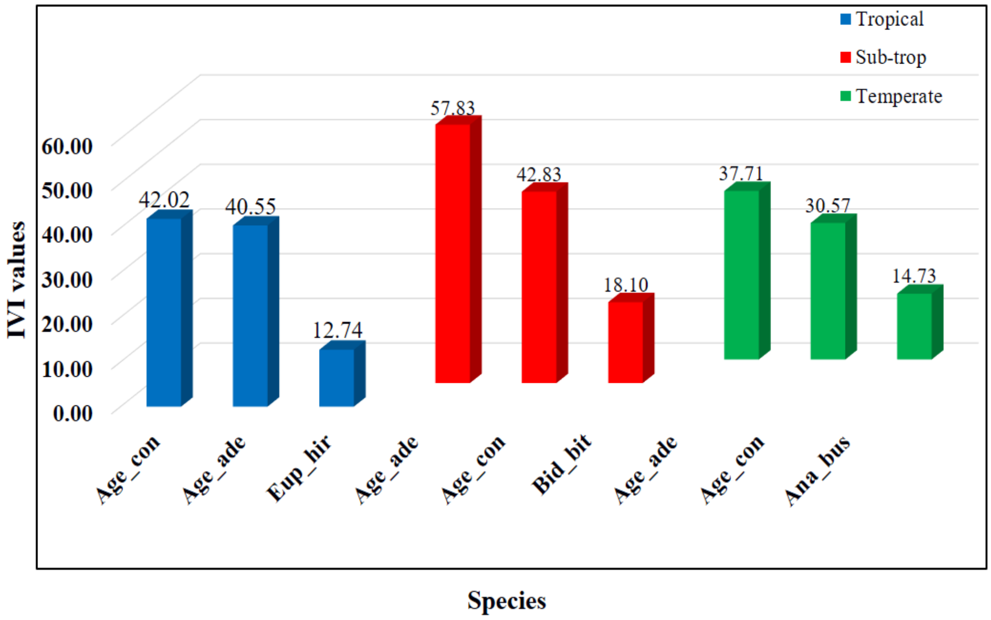


Figure 12: Therophyte species present in different ecological zones having the highest IVI values.

the highest IVI value (42.02) in tropical region, but *Ageratina adenophora* obtained the IVI values: 57.83 and 37.71 in Sub-trop and temperate region respectively (**Figure 12** & **Annex 4**). These two species were followed by *Euphorbia hirta* in tropical, *Bidens biternata* in sub-tropical and *Anaphalis busua* in temperate region.

2.5 Discussion

Scientists believe that a system is needed to catalog each species' name and geographic range in order to protect the variety of life on world

2.5.1 Floristic diversity

The vascular plant diversity reports that there are altogether 606 vascular plants species related to 123 families and 418 genera. The dicot achieved the maximum species and gymnosperm obtaind the least species in wild stage. In dicot, leguminosae (Fabaceae) and *Ficus* and *Thelypteris* are the largest family and genera respectively. Similarly, Poaceae and Pteridaceae are families containing more species in monocot and pteridophytes respectively. This information shows that this area (Arghakhanchi district and surrounding region) is also rich in biodiversity in tropical to subtropical region of west Nepal. Panthi and Chaudhary (2002) reported 501 species of angiosperm in Arghakhanchi district. On the basis of secondary sources, Nepali *et al.* (2020) reported 597 vascular plant species in this district. There was not found any endemic species in the study area. However, 312 endemic species of floweing plants belonging to 46 families and 126 genera are reported in Nepal (Rajbhandari & Rai, 2017). Almost endemic species are reported from areas of higher elevation in Nepal.

The findings indicate that, Phanerophytes and Chamaephytes have the highest and lowest species richness (gamma diversity) respectively. The presence of the highest speciees richness of Phanerophytes was also reported by Candido *et al*. (2019) in savannas in Brazil and by Severin *et al.* (2020) in Canary Islands, Africa. Almost species of Phanerophytes are perennial and can survive at areas having annual rainfall low to high (< 150 to > 500 mm) (Danin & Orshan, 1990). According to Al-Yemeni & Sher (2010) and Kambhar & Kotresha (2012), Therophytes, an annual plant group with an ideal range of rainfall between 200 and 500 mm, were prominent in dry deciduous forests. Similarly, Chamaephytes (Al-Hawshabi *et al.*, 2017) and Hemicryptophytes (Candido *et al.*, 2019) were flourished in grasslands. This supports the presence of less diversity of Chamaephytes, Hemicryptophytes and Therophytes in forest site of this study area. The variety of plant life significantly reflects local climate, as well as to some extent plant-biogeographic relationships. This result concludes that the floristic spectra of life form is variable according to elevation and geography of the area.

Phaneropytes and Chamaephytes have the highest and lowest mean alpha diversity value respectively. In contrast to this finding, Therophytes and Phanerophytes were the categories with higher and lower mean α diversity, respectively in Crete, Greece (Lazarina *et al.*, 2019). Alpha diversity is affected differently by various climatic, topographical, and biogeographical factors in different grains (Sabatini *et al.*, 2022).

The overall flip over species found in two adjacent sites or plots makes up the beta diversity. According to the result, the Phanerophytes and Chamaephytes exhibit high and low beta species diversity. Contrary to this findings, Therophytes and Phanerophytes in Crete, Greece, had the highest and lowest levels of β diversity, respectively, throughout the elevational gradient (Lazarina *et al*., 2019). Home-grown environmental structures had significant role in determining the beta variety of the many features and components of functional and evolutionary variety (Hill *et al.,* 2019). Diverse vascular life-forms and useful characters react to variations in heat and moisture in a variety of ways. Various climatic, topographical, and biogeographical factors of any place influence in species compositional variation along with alpha diversity.

2.5.2 Biodiversity indices

Elevation is a complicated mix of climatic variables, which influences on the structure and organization of communities (Stevens, 1992). In addition to temperature fluctuations and the precipitation, the qualities of soil present in varied elevation greatly influence on plant distribution and abundance (Polis, 1991). The environmental effects of elevation on species variety and the distribution of living forms can noticeably explain by temperature, soil moisture, and nutrients (Mahdavi *et al*., 2013).

A rapid way to distinguish between various areas, ecosystems, or populations of plants and animals is to use biodiversity indices. In ecological data, the Shannon diversity index, Simpson index and evenness values vary from 1.5 to 3.5, 0 to 1 and 0 to 1 respectively. The mean value of Shannon-Wiener index (2.75), Simpson index (0.89) and evenness (0.84) of total vascular plant species show the higher value in comparison to individual life forms. The Simpson index and Shannon-Wiener diversity index results show that Phanerophytes have the highest and Chamaephytes have lowest value. The diversity index values $2 \geq H \leq 3$ and $D \geq 0.8$ indicate the the total vascular plants and Phanerophytes show the moderate diversity with high abundance. Other life forms show the less diversity. This result was supported by Sharashy (2022). On the basis of Pielou's evenness index value (E), $0.75 > E \leq 1$ declears that all life forms besides Geophytes are stable and evenly distributed in the study area. Evenness is a degree of the comparative richness of the diverse species creation up the fruitfulness of an area (Supriatna, 2018). The higher values of diversity indices indicates that this study area is ridiculous in total plant diversity of vascular plant and Phanerophytes, but all plant life form besides Geophytes are evenly distributed throughout the study area. These indices may forecast the state of the environment and are more reflective in nature.

The dissemination and abundance of many varieties have changed throughout period, and biodiversity indexes are frequently employed to quantify these changes and track management goals (Giljohann *et al*., 2017). It is appropriate to compare the diversity recorded by one index with that measured by another since biodiversity indexes differ in their calculation and interpretations. The values will undoubtedly change based on other organisms or the situation at hand **(**Okpiliya, 2012).

2.5.3 Species richness on the basis of forest types

Based on the local flora' features, many types of forests were identified. The finding indicates that various forest types are present in both aspects. The forest types on the north and south sides are found significantly different. Although mixed Pine (*Pinus roxburghi, Shorea robusta, Castanopsis indica* and *Schima wallichii)* forest has the maximum species abundance in the north aspect, while mixed *Shorea* forest has the more species richness in the south aspect. Every plant community has a dominating species that it is named after, and it is distinguished by a unique set of related species and their combined architecture (Pickett *et al.,* 1992).

In summary, this finding demonstrate that variety of vascular plant species and the plenty of various plant life forms have clearly defined throughout the examined elevational gradient. It suggests that the occurrence of various life forms in tropical and subtropical environments depends on the environmental heterogeneity, which also has an impact on the physiognomy and organization of the local communities.

The result supports at higher elevations, energy-related factors likely directly impact species abundance, whereas areas of lower altitudes, the outcome is more influenced by moisture (Bhattarai *et al.,* 2004).

2.5.4 Vegetation analysis

The distribution of certain species within the community, as opposed to the community as a whole, can be studied using statistical methods to study vegetation (Ashby & Stevens, 1935). The IVI which measures the floristic variety of forest systems, is an essential component in guessing out a species' ecological importance in a particular ecosystem (Gonçalves *et al.*, 2018).

The result of quantitative vegetation analysis shows that *Capillipedium assimile* have the highest IVI value in all three ecological zone under Geophytes life form. This is the most dominat and abundant species among vascular species existing in this area. The research of Pandey & Bajracharya (2010) in Shivapuri National Park supports that *C. assimile* is dominant species in subtropical and temperate forest. Other dominat species are: *Saccharum spontanuem*, *Oxalis corniculata. Cynodon dactylon, Imperata cylindrica* and *Reinwardtia indica* most, in which of them are monocots. Among the Therophytes species, *Ageratina adenophora* and *Ageratum conyzoides* got the first and second position in all parameters:

The most prevalent woody species among Phaneropytes is *Shorea robusta.* Sal forest predominates on the southern slope of hills lower than 1000 meters. Sal is found combined with many species, such as *Pinus roxburghii, Schima wallichii, Castanopsis indica,* etc., in the area below 1500 m in both aspects. Godar (2021) also found that the *Shorea robusta* is the dominant woody species in Chure range of west Nepal.

The biodiversity of Himalayan area is vulnerable by quick alterations due in climatic and edaphic factors caused by global warming and anthropogenic activities. The degree and appearances of climatic variation, prior information of long term change the pattern of forests are fundamental status of biodiversity (Chakraborty *et al.,* 2018).

2.6 Conclusions

This research reports that there are altogether 606 vascular species related to 123 families and 418 genera in Arghakhanchi district and adjoining areas. Among the plant taxa, dicot obtained the chief and gymnosperm obtained the least species richness in wild stage. According to the Raunkiaer's life forms, the Phanerophytes (265 species) and Chamaephytes (37 species) have the highest and lowest species richness, respectively. The mean alpha diversity were found higher in Phanerophytes and low in Chamaephytes respectively. The great value of Shannon-Wiener index (2.75) and Simpson index (0.89) in total vascular plant species shows that the study zone is also moderate rich in biodiversity. *Ageratina adenophora* and *Ageratum conyzoides* are dominant as well as frequent species in therophytes in tropical to temperate regions. *Cynodon dactylon* and *Imperata cylindrica* show the dominancy in Hemicryptophytes. The *Shorea robusta* found the leading species of Phanerophytes in tropical and Sub-tropical region. This shows the forest of tropical and Sub-tropical region in this area is dominated by *S. robusta.* The *Capillipedium assimile* is the dominant and frequent species of in overall vascular plants. There is significant different in species richness in north and south aspects of hills.

3. SPECIES-ENVIRONMENT RELATIONSHIP

3.1 Introduction

Mountains, the most remarkable geological features in the world, cover around 25% of the planet's surface area and are home to at least a third of all plant species because they alter climatic conditions (Korner, 2000; Khan, 2012). Along with the significant difference in topography, climate, and soil composition, the mountainous region serves as a home for a many creatures.

The elevation gradients provide biological hotspots or significant species variety in communities and variation in communities within short distance, which is observable in Himalaya as well as other regions. Elevational grades offer a great range of diverse eco-friendly conditions in addition to creating microclimates that affect the construction and alignment of plant species in each micro area (Rehman *et al.*, 2022).

All alive creatures are directly or indirectly dependent on number of the environmental factors to run their biophysical processes and to survive in particular habitat (Chu 2017). Life means the energy transfers of energy and matter between living things and environment. Lack of transfer of energy and shortage of required nutrients leads towards the death. The interactions of abiotic elements like: temperature, moisture, and soil nutrients with biotic variables and biotic interactions within and between species have an influence on the dispersal of plant, animal, and microorganism species (Kraan *et al.*, 2010). Not every essential component equally contributes to the growth or spread of the organism. The important eenvironmental issues that affect plant development contain light, temperature, water, moisture and nutrition (Thammanu *et al*., 2021).

Biochemical structure and function, as well as species distribution, are primarily determined by soil nutrients like: nitrogen, magnesium, calcium, phosphorus, potassium and pH (Peoples *et al.,* 2014). Differences in nitrogen and phosphurus concentrations between ecosystems is the source of the variance in species composition with respect to ecological issues (Brant & Chen, 2015; Guignard *et al.,* 2017). Nitrogen is a necessary element of all enzymes and collaborates with carbon dioxide to significantly increase ecosystem production and carbon sequestration

(Reich *et al*., 2006), while, phosphorus is necessary for the synthesis and maintenance of proteins and lots of other processes. Both of these serve as primary limiting elements of biochemical processes (Gusewell, 2004), and Topography alters the spatial dispersal of organic matter buildup in the soil and regulates the soil nutrients that are available to plants (Enoki *et al*., 1996; Hirobe *et al.,* 1998). Numerous physiological processes, with the regulation of cellular development and timber production, xylem-phloem water amount and movement, nutrition and metabolite transportation, and stress reactions, are aided by potassium (Sardans & Peñuelas, 2021). Similarly, the soil pH, termed also as "master soil variable" (Neina, 2019), that marks the biological, physical and chemical parts of soil and has an impact on plant development and biomass output (Neina, 2019). The factors in the soil like water, nutrients, and pH may explain the spatial distributions of plant species (Sollins, 1998). Besides, these edaphic factors, another factor which plays a critical role in species distribution is RRI. The combined value of the slope, aspect, and latitude measurements is known as the relative radiation index (RRI) (Ôke, 1987). It helps to equate the solar energy received by regions with the same latitude (Mamassi *et al*., 2012). Solar radiation is the radiant energy that comes from the sun and powers photosynthesis as well as giving the earth heat and light.

The majority of research to date is focused on broad categories of soil type and summary axes of species composition, enlightening that communities change with soil (Toledo *et al*., 2012). Many studies (Sherchan *et al*., 1992; KC *et al*., 2013; Chalise *et al*., 2019) have documented a consistent reduction in the fertility level of forest soil in Nepal as a result of heavy grazing, forest degradation, landslides, and soil erosion. Using the right quantitative and statistical analyses along the elevational ascent, more than 90% of the inconsistency in the species variety could be described (Chawala *et al*., 2008). This work is focused on estimation of role of ecological variables in species wealth as well as species conformation. The overall goal is to study the link between ecological factors and species alignment in Arghakhanchi district and its adjoining areas.

3.2 Literature Review

Botanists from across the world and Nepalese botanists have not sampled the lowlands as thoroughly as they have the upper elevations in Nepal, probably because it is believed that the higher Himalayan region is a hotspot of species and thus a major draw for botanists (Dobremez, 1976). In Nepal, phytogeography rather than ecology has dominated botanical research. This chapter focuses on a few ecological studies that looked at species distribution or species composition.

3.2.1 Ecological studies outside Nepal

The first focus of botanical studies was solely on the collection and counting of plants, neglecting any other accessory elements. In the early 1700s, Antony Van Leewenhoek made significant contributions to the study of the food chain and population control. He also shared with his friend and botanist Richard Bradley his understanding of biological production. It is regarded as the pioneering study on the interactions between species and environments (Odum & Barrett, 2015). However, Huckel termed the study of these relationships as Ecology in 1869.

Numerous scientists have investigated the ecological processes in various plant and animal species. Emerson & Kolm (2005) examined the positive association among species variety and rate of variation by using data on plants and insects of the volcanic archipelagos of the Canary and Hawaiian Islands. They assumed that endemism rises as the number of species grows. According to them, diversification is substantially correlated with species number even after adjusting for a number of significant physical characteristics of habitats**.**

On investigation of plant species distribution in the Bagh District of Azad Kashmir province, Pakistan, Shaheen *et al*. (2011) discovered that Evenness- 0.23 to 0.61; Simpson's diversity stretched from 0.85 to 1.96; Menhinick's diversity, 1.49 to 1.37; normal species abundance per site, 36 to 40 and maturity index, 41 to 44. A hemicryptophytic life form predominated in the local alpine flora, and the negative association between their diversity and richness and the altitudinal gradient confirmed this.

The condition of the soil has an impact on plant dispersion as well. Xian-Li *et al.* (2008) studied on relationship of the plant species, soil, and topographical factors in Minjiang River valley, Sichuan Province, China from elevation 900-3600 m. According to cluster analysis (CA), good soil quality having enough nutrients and low solar incident radiation were all related to high plant diversity, cover, and height. Plant diversity was mostly connected to soil water content, which was primarily influenced by soil texture, according to correlation investigation as well as multiple linear stepwise regression analysis (clay content). On the geobotanical study done by Koptsik *et al.* (2003) revealed that there is a nearby association between species assortment of phytocenoses and soil characters in the Russkii Sever National Nature Park, Russia. Soil pH, together with the concentrations of exchangeable calcium, potassium, and magnesium, is a factor determining variations of species diversity indices for vascular plants and bryophytes in forest biogeocenoses.

Similarly, the hill aspect and soil are crucial in determining plant dispersion. Maren *et al*. (2015) examined woodland physiognomies, soil properties and carbon stocks of south and north-facing slopes in semiarid valley of trans-Himalayan region. *Pinus wallichiana* was the leading and *Juniperus indica* the co-leading species in two aspects, whereas *Abies spectabilis* and *Betula utilis* were only documented in north-facing forests. Their result suggested that physiographic factors mark the vegetation of mountain through their straight effect on moisture and radiation, but that human disruption also shows an important role upsetting flora and soil features in a semiarid situation.

Many studies show that the climate is the stronger factor for species distribution. Cottle (2004) declared that Climate can act upon soils secondarily through inducing, extent and nature of flora and inorganic input into soils. Growth rates of vegetation rise with temperature and moisture, as does the rate of organic decay. Maximum decomposition occurs between 25°C - 35°C, therefore an increased rate at which organic material is incorporated into the soil with rising temperature. Morrison & Mathewson (2015) studied how plant spreading have changed in habitat of wildlifes in the tropics during the last two centuries. The causes are low rainfall, melting glaciers, land cultivation and the propagating of new species by humans. According to him, these changes could have caused the large-scale vegetation shift in the tropics than other areas. This reading emphasized how nature has been moved in reaction to climate change and how it will be continued to do so in the coming.

The Himalaya is a major center for species, and like other mountain ranges, this area's elevation has an impact on the majority of other ecological aspects. In the whole western Himalaya, Oommen & Shankar (2005) analyzed the distributions of woody plant species and found a unimodal trend with respect to elevation. The temperate species also presented a bimodal association with temperature, while tropical species abundance followed temperature and area. Sharma *et al*. (2014) studied in Sangla Valley of northwest Himalaya on the structure of vegetation and its trend along the altitudinal gradient. They explained that the Himalayan biodiversity hotspots facing rapid damage in floristic diversity and changing pattern of vegetation due to various biotic and abiotic factors. The study found 320 species related to 199 genera and 75 families around 16 communities, with Asteraceae, Rosaceae, Apiaceae, and Ranunculaceae dominant. Among genera, *Artemisia* tracked by *Polygonum, Saussurea, Berberis* and *Thalictrum* were dominant. Tree and shrub's density extended from 205 to 600 and from 105 to 1030 individual per hectare, respectively, whereas herbs stretched from 22.08 to 78.95 individual/m^2. According to Bhagwat (2012), the knowledge gap is particularly severe in remote mountainous regions of the Himalayas where high species richness is combined with intricate topography and inaccessibility. Species assemblages of some groups and from some low land as well as high land regions still remain relatively unexplored.

The elevation plays an important effect in determining the pattern of species richness in the majority of studies on elevation-dependent plants. The study of Habib *et al*. (2011) investigated changes in vegetation assortment and species richness along an elevation between 900-3000 m at Garhi Dopatta Hills, India. Species diversity and richness values in the tree layer were high in the middle part of the altitudinal gradient. It decreases both towards upper and lower elevation, which was due to deforestation, human interaction, and encroachment. Xu *et al*. (2016) studied on altitudinal patterns of biological diversity and their underlying mechanisms for biodiversity conservation in Jade Dragon Snow Mountain, Tibet by applying two methods: 1 - power-law relationship between richness and area, and method 2 richness counted in equal-area altitudinal bands. They found that seed plant species abundance, genus richness, family richness, and species richness of trees, shrubs, herbs and Groups I–III (species with elevational range size 500 m, respectively) show distinct hump shaped patterns along the equal-elevation altitudinal gradient.

Lazarina *et al*. (2019) investigated the patterns of diversity and their mechanisms of diverse plant life forms on Crete, Greece and found that α- diversity, β- diversity, and - γ diversity are all strongly correlated with the wide variations in elevational and environmental ranges of living forms. The alpha and beta diversities declined with elevation, while the β-diversity followed a hump-shaped relationship with each living group's peak being distinct. This demonstrates that species arrangement is determined by the size of the species pool and type of life, in contrast to other deterministic processes that operate similarly for many life forms. In lowlands, hotter, drier conditions and rising human activity influence species composition, whereas in higher elevations, large-scale forces that determine the size of the species pool overcome local biological processes

3.2.2 Ecological studies in Nepal

Numerous ecological studies have been carried out in Nepal by Nepalese or international scientists. Studies have revealed that both interpolated and empirical data exhibit the elevational unimodal species richness.

Bhattarai & Vetaas (2003) evaluated the relation between plant species richness in different life forms to different climatic variables such as potential evapo-transpiration (PET), mean annual rainfall (MAR) and moisture index (MI) along east Nepal. They used observed data of all vascular species from eastern Nepal from 100 - 1500 m and total species (excluding ferns), shrubs and trees showed unimodal patterns with elevation. The woody climbers and ferns showed a positive monotonic trend with elevation. Climbers, herbaceous climbers, all herbaceous plants, grasses and forbs showed no substantial relation with elevation.

Baniya (2004) studied the species richness and composition patterns along abandoned fields in subalpine trans-himalayan zone, Central Nepal. Their study showed that the species abundance and conformation outlines are highly scale dependent at all levels of spatio-temporal gradients. Some variables such as soil is extremely important at the local-scale species composition and richness patterns. Climatic factors are highly important at the broad-scale but can also be influential at local scales too. Species richness patterns also highly depend on the studied taxonomic set of species, their functional types, life-forms and their geography **(**Baniya *et al.* 2012).

Bhattarai *et al*. (2014) checked the species richness design with elevation ascent and compared the empirical study with regional pattern and regressed to diverse ecological parameters including all the habitat types and vegetation. On regression, total vascular plants along with the life forms against elevation, and other environmental parameters, they found that species richness of total vascular plants and all life forms showed a unimodal pattern with elevation having a peak at an elevation of 3500 m a s l.

Magraw & Detling (2012**)** examined indicators species such as species richness and diversity, unique species, stand composition, and structure by comparing vascular communities in four flora types in the eastern Middle Hills (1000-3000 m elevation) of Nepal. Primary forests, deforested areas, large cardamom (*Amomum subulatum*) plantations, and conifer plantations. Primary forests (229 species, 30%) and conifer plantations showed statistically significant greater species richness than deforested and cardamom plantations sites. Deforested areas contained 178 species, sparse and suited to visible habitats. Cardamom plantations contained 174 species and were characterized by an *Alnus nepalensis* overstory and *Amomun subulatum* in the understory. Conifer plantations characterised by *Cryptomeria japonica, Pinus wallichiana,* or *Pinus roxburghii.* Out of 217 species encountered, only 16% were unique to this vegetation type, although species diversity was comparatively high (Shannon-Wiener index: 3.34).

Grytnes & Vetaas (2002) came to the conclusion that the species richness in the Himalaya displayed a unimodal pattern of diversity, with the largest richness of Nepal's flowering plants between 1500 m and 2500 m asl. Aspects and elevations have the biggest influence on restricting plant species and community kinds in mountainous areas (Chawl *et al*., 2008; Khan *et al*., 2015). But there was a clear linear trend in the variety of tree species studied in the Palpa district (Mahato, 2006).

Kharal *et al.* (2018) compared the fertility parameters of soil: soil pH- 5.17 & 4.74, total N- 0.14 & 0.18 %, available P -2.89 & 4.15 mg kg^{-1} and available K -36.80 & 77.50 mg kg^{-1} in grazing land and forest soil respectively with soil pH 6.61, total N 0.12%, available P - 41.07 mg kg^{-1} and available K - 130-2 mg kg^{-1} in vegetable farm land in Dhading district. In comparison to soil from vegetable farms, grassland and forest soil had lower pH, P, and K levels but higher levels of nitrogen.

Panthi & Chaudhary (2002) worked on the angiosperm flora of Arghakhanchi district, listing a 501 species related to 373 genera and 113 families. Panthi *et al.* (2007) studied the species richness and composition in the south and north aspects of the dry valley of Manang between 3000- 4000 m a.s.l. Species richness was found considerably higher on the north facing slope than on the south face.

3.3 Material and Methods

The information about environmental factor was gathered by the following methods**:**

3.3.1 Physiographic information collection

The coordinates (latitude and longitude) and elevation of individual sampled site was determined by using handheld Garmin GPS etrex10 at field. Similarly, slope at each site was measured by a handheld clinometer SUUNTO PM-5/66 PC OPTI.

3.3.2 Soil sample collection

Around 1 kg soil was collected from 15 centimeters under the soil surface at four corners of one quadrat in sampled site. The collected soil samples were carried for analysis in laboratory.

3.3.2.1 Soil nutrients analysis

The soil parameters: pH, nitrogen, phosphorus and potassium present in each soil samples were determined in Soil, Water and Air testing laboratory (SWAT), Babarmahal, Kathmandu by the following protocols.

3.3.2.1. a Soil pH determination

The pH of soil was estimated with the help of pH meter by ensuing the technique given by Singh *et al.* (1999).

3.3.2.1. b Nitrogen estimation

The total nitrogen present in soil samples was determined by following the Alkaline Permanganate Method (Black, 1965). The following formula is used to calculate the nitrogen content in soil.

$$\text{N (\%)} = (\text{A} - \text{B}) \text{ x normality of H2SO4 X } 0.014 \text{ x } \frac{100\ (\text{g})}{\text{Wt. of soil (g)}}$$

$$\text{Available N(kg per ha)} = \text{N (\%)x } \frac{2240000}{100}$$

Where, A = Volume of standard H_2SO_4 required for soil sample

B= Volume of standard H_2SO_4 required for black sample

3.3.2.1. c Phosphorus estimation

The total phosphorus present in soil samples was determined by following the Olsen's Method (Olsen and Sommers, 1982). The following formula is used to calculate the phosphorus content in soil.

$$\mathrm{P\ (ppm)} = \frac{\mathrm{GR \times 50 \times 5}}{\mathrm{Corrected\ Ht.\ of\ soil}}$$

Where,

GR – Concentration of P in analyzed sample. (Read from std. curve)

$\mathrm{P\ (kg/ha)} = \mathrm{P\ (ppm)} \times 2.24$

3.3.2.1. d Potassium estimation

The potassium present in soil was estimated by Flame Photometer method (Knudsen and Peterson, 1982). The following formula was used to estimate potassium:

$$\mathrm{K\ (kg/ha)} = \mathrm{Reading\ from\ graph\ K\ (\mu K/ml)\ in\ extract\ (R)} \times 5 \times 2.24 \times \mathrm{Dilution\ factor\ (Df)}$$

3.3.3 Climatic data collection

There are 2 climatic stations: Khanchikot and Sandhikhark in Arghakhanchi district and one station: Tamghas in Gulmi district. The required climatic data (temperature and rainfall) of 10 years (2010-2019) (**Figure 4**) of recorded in three stations: Khanchikot, Sandhikharka and Tanghas was received from the Department of Hydrology and Meteorology (DHM, 2021).

3.3.4 Plant composition data

The same data applied for estimation of species richness and vegetation analysis was used in this analysis

3.3.5 Statistical analysis

The following methods were used for statistical analysis**.**

3.3.5.1 Elevational-species richness relationship

The relation between species richness and elevation was determined by apply of generalized linear model (*GLM*) regression (Turner, 2008) in 4.0.2 version in R software (2023).

3.3.5.2 Correlation between species richness and environmental factors

The correlation of species with all environmental factors (elevation, RRI, soil pH, Nitrogen, Phosphorus, Potassium and slope aspect) was determined by Pearson's correlation method (Berman, 2016) in R software (4.0.2).

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma}(x-\bar{x})^2\sqrt{(y-\bar{y})^2}}$$

Where, r = Pearson's correlation $\bar{x}$ and $\bar{y}$ are the means of x and y variables

3.3.5.3 Relation of species composition with environmental factors

The relation between species arrangement and selected environmental factors is estimated by the following formulae:

3.3.5.3.1 Permutational analysis of variance

The environmental variables show the variable response in individual or coordinate forms with species composition. The permutation multiple ANOVA (PerMANOVA), an applied distance-based or distance matrix method, is used to test the association or similarity of species composition with covariates of interest i. e. environmental factors**.** This PerMANOVA was calculated by use of ADONIS function of vegan package in r software (Anderson, 2006; Oksanen *et al*., 2018).

3.3.3.5.2 Variance inflation factor

When there is multicollinearity between several independent variables in a multivariate regression model, results may be compromised (Potters, 2022). Therefore, the amount that multicollinearity has inflated a regression coefficient's variance can be determined using the variance inflation factor (VIF) (Forthofer *et al*., 2007).

3.3.3.5.3 Ordination

The relation of species occurrence in ecological factors was clarified by ordination or multivariate analysis. On the basis of axis length and eigenvalue of DCA, the appropriate method of ordination was selected for further analysis. According to Leps and Smilauer (2003), the length of the gradient of the DCA axis I for the entire data set was larger than 2.5 standard deviation units for unimodal ordination methods (like the CCA). On the other hand, when the gradient's axis length is less than 2.5 SD units, linear ordination approaches are preferable (e.g., RRA). The variance of data sets can be analogously understood as the inertia component of the CCA. This ordination was completed in vegan package in R version 4.1.2 (Oksanen, 2018).

3.4 Results

3.4.1 Elevational Species Richness Pattern

The vascular species abundance (alpha diversity) present 100 m countor elevation of entire study area regressed by *GLM* method to show relation with elevation. Total species richness increased continuously when the elevation increased and above than 1300 m, the richness started to decrease following the statistically significant (R^2=0.78 at $p < 0.05$) unimodal structure with elevation (**Figure 13 A**). Similar to this, even though the highest species' elevation varies, each individual life form species revealed a statistically significant hump-shaped structure versus elevation (**Figure 13 B**).

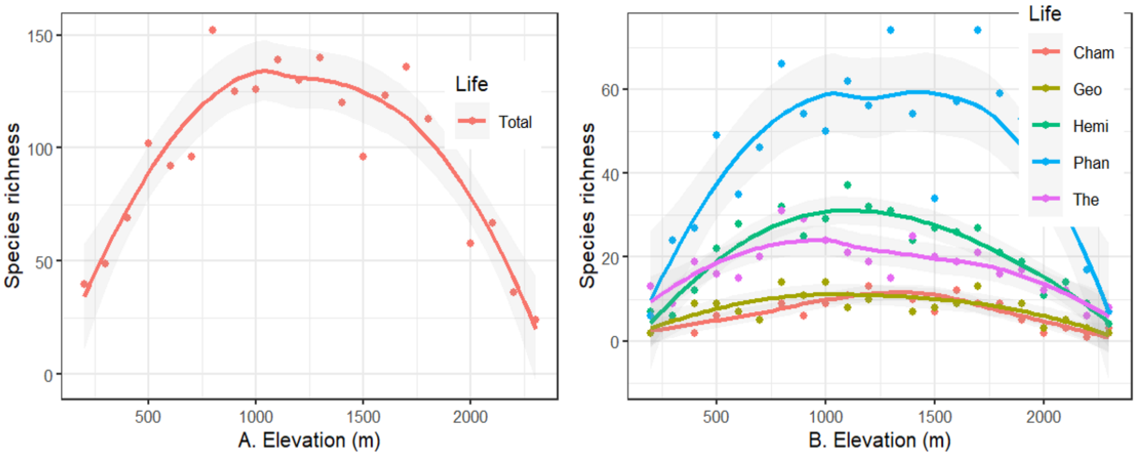


Figure 13: Elevational patterns of alpha species diversity. **A.** Total vascular species (R^2=0.78, at $p < 0.05$), **B**. Life forms: - Chamaephytes, Geophytes, Hemicryptophytes, Phanerophtes and Therophytes (R^2 values- 0.75, 0.55, 0.84, 0.68 and 0.64 respectelvely)

The elevation range is not equal in two aspects of the study area. However, the range on the north face was increased from 725 to 2288. The elevation range of the sampled sites on the south aspect was found to be 200-2100 m. Due to the area's steepness, sampling efforts on the south side of Resunga Hill (2300 m) were unsuccessful. Therefore, in equal quadrats of the same elevation range (700-2100 m), species were selected to illustrate the association between species richness of two features and elevation.The species richness present on both aspects followed the linear relationship which was not statistically significant (**Figure 14 A).**

Similar to this, *GLM* regression also revealed species prevalent throughout the entire elevation range of both aspects. Plant species in the south displayed a no-significant relationship against elevation, whereas those in the north displayed a significant unimodal correlation (**Figure 14 B).** The richness of the north appears like a bimodal structure.

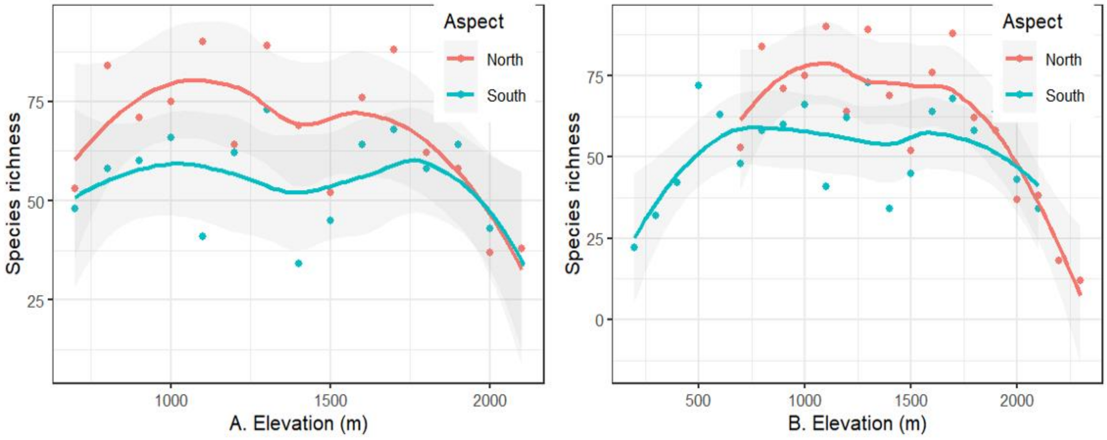


Figure 14: The elevational species richness pattern with individual slope aspect (**A**) On the basis of equal elevation in both aspect (North R^2 =0.26 and South R^2 =0.03 at $p < 0.05$) and (**B**) On the basis of natural elevation range (North- R^2 =0.72 and South R^2 =0.37)

3.4.2 Relationship of Environmental variables with species richness

Elevations of the study area is ranged between 200 and 2300 m. In several sampled plots, the value of environmental variables was revealed to vary (**Table 4)**.

Table 4: The value of environmental variables in plots of study area (mean value ± standard deviation).

Elevation (m)	RRI value	pH	N		P		K	
			%	Kg/ha	%	Kg/ha	%	Kg/ha
200 -2300	0.33 ± 0.47	5.78 ± 0.18	0.76 ± 0.28	13948.95	0.002 ± 0.001	34.49	0.021 ± 0.01	354.5

The correlation of species richness with environmental variables was evaluated using a Pearson's correlation approach. Only Geophytes, Hemicryptophytes, Therophytes and total vascular species showed a statistically meaningful link ($p < 0.05$) with elevation and nitrogen according to the findings (**Table 5**). Chamaephytes showed significant negative relationship with only elevation.

Table 5: The correlation coefficient values of environmental variables with species richness

Life forms	Elev	RRI	pH	N	P	K	AspS	AspN
Phane	-0.1	0	-0.08	-0.07	-0.03	0.06	0.06	-0.06
Cha	-0.18*	-0.1	0.05	-0.11	-0.08	-0.07	0.12	-0.12
Hemi	-0.23**	0	0.01	-0.17*	-0.07	-0.13	0.12	-0.12
Geo	-0.15*	-0.17*	0.07	-0.16*	0.04	-0.01	-0.2	0.2
Thero	-0.16*	-0.05	0.06	-0.18*	-0.09	-0.01	0	0
Total	-0.2**	-0.04	-0.02	-0.18*	-0.06	-0.01	0.04	-0.04

Significance: p value 0.05 “*”, 0.01 “**” and 0.001 “***”

3.4.3 Relationship of species composition with environmental variables

The species composition indicates the distribution or abundance of species in the overall study area. To evaluate the similarity of species (species composition) concerning environmental factors, a permutation multiple ANOVA (PerMANOVA) was used (ADONIS function of vegan package; Anderson 2001; Oksanen *et al*. 2018). The species composition was significantly correlated ($p < 0.05$) with each of the edaphic variables (pH, N, P, and K). But, the association between species composition and elevation and climate did not appear to be particularly strong (**Annex 5**). According to the result, the strong link between species composition and elevation in combination with other climatic and edaphic factors was demonstrated.

Ordination methods were used to study the intricate interaction between ecological factors and species composition. Grubbs' test of outliers was used to correct the outliers in the species composition (1969). To get around the drawbacks of correspondence investigation, detrended correspondence analysis (DCA) was created. By flattening the arch and rescaling the sample locations along one axis, DCA gets around these issues (Holland, 2008). An axis length of DCA 1 of more than 2.5 and eigenvalue of first axis more than 0.5 (according to ter Braak, 1986) suggested a nonlinear relation of species composition with environmental variables (**Annex 7).**

Before CCA analysis, the multicollinearity among the environmental variables (the test of goodness of CCA) was tested through the variance inflation factor method (Forthofer *et al*., 2007). A low score in the vif test demonstrated that environmental factors and response variables do not exhibit multicollinearity (**Annex 6**).

To demonstrate the link between species and environmental factors, the direct gradient CCA method was used. I found a connection among the species composition of plants and environmental factors in a forest with inertia values between 10.98 (for geophytes) and 16.51 (for Hemicryptophytes, $P < 0.05$) (**Annex 8**). This result showed that the constrained environmental variables explained only 4-7% of species distribution leaving the remainder influence for unconstrained variables.

Out of the plant life forms studied, Phanerophytes and Hemicrptophtes had the highest restricted eigenvalues (0.46 and 0.28, respectively) in CCA1. The first and second axes of the CCA exceeded 50% of variance for every life species (**Annex 9**).

According to the Biplot scores of CCA result, elevation and nitrogen showed the strongest relationships with life form species in this study. The Hemicryptophytes, Phanerophytes and Therophytes showed a high positive correlation (canonical correlation $r > 0.65$) with elevation and nitrogen, whereas Chamaephytes, and Geophytes displayed significant negative correlations in CCA1 (**Table 6**). Chamaephytes, Hemicryptophytes, and Phanerophytes exhibited strong negative correlations to potassium concentration on CCA2 axis, whereas slope aspect showed a substantial positive relationship with Geophytes, and Therophytes on CCA2 axis. According to results of centroids for factor constraints (**Annex 10**), the Geophytes and Therophytes had the significant positive relation on south but negative relation on north aspect. The association between various life form and environmental conditions, as indicated by ordination plots of CCA, is shown below.

Table 6: Biplot scores of the two first CCA axes of life form species with environmental variables

Life forms	Axis	Elev	RRI	pH	N	P	K	Aspect
Phanerophytes	CCA1	0.99*	0.17	-0.25	0.71*	0.29	0.47	-0.08
	CCA2	0.03	-0.41	0.56*	-0.12	0.16	-0.56*	0.24
Chamaephytes	CCA1	-0.9*	-0.28	0.52*	-0.74*	-0.29	-0.28	0.42
	CCA2	-0.03	-0.39	0.29	0.08	0.45	-0.65*	-0.05
Hemicryptophytes	CCA1	0.96*	-0.06	-0.3	0.65*	0.43	0.38	-0.23
	CCA2	-0.03	-0.35	0.51*	0.3	-0.29	-0.58*	0.49
Geophytes	CCA1	-0.88*	0.04	0.15	-0.65*	-0.46	-0.32	0.05
	CCA2	0.05	0.35	-0.03	-0.05	0.08	-0.12	0.78*
Therophytes	CCA1	0.88*	0.03	-0.27	0.74*	0.52*	0.31	0.2
	CCA2	-0.2	-0.14	-0.24	-0.24	-0.22	-0.05	0.85*

*Significance, $p < 0.05$

3.4.3.1 The Phanerophyte species

The Phanerophytes species showing high scores on CCA1 were *Borassus flabellifer* (r=1.45), *Cinnamomum glanduliferum* (r=1.39), and *Clematis acuminata* (r=1.38), whereas in CCA2, species showing high species scores were *Miliusa velutina* (r=2.61) and *Careya arborea* (r=1.78) (**Annex 11**).

The CCA Biplot demonstrated that the majority of Phanerophytes did not show the strong impact with most of the factor studied here. The high distribution of species like: *Borassus flabellifer, Rubus paniculatus, Rubus rugosus, Clematis acuminata, Elsholtzia fruticosa, Berberis aristata, Eriobotrya dubia, Fraxinus floribunda, Pyracantha crenulata,* and *Rubus paniculatus* was strongly positively correlated to elevation and nitrogen levels. In the localities with high soil potassium content, the species *Hypericum uralum, Cinnamomum tamala, Osbeckia stellata, Quercus glauca,* and *Syzygium nervosum* had high abundances. Similarly, the species *Ficus nerifolia, Gaultheria fragrantissima, Schefflera venulosa, Spermadictyon suaveolens* obtained high frequencies at sites with high phosphorus concentrations in soil. High frequencies of the phanerophytes species *F. semicordata*, *Marsdenia roylei*, *Kydia calycina*, *G, fragrantissima*, *S. venulosa*, *S. suaveolens* and *Trema tomentosa* were also found in localities with comparatively high soil pH levels.

High frequencies of the Phanerophytes species *Erythrina stricta*, *Clerodendrum philippinum*, *Yua thomsonii (*Syn. *Cayratia thomsonii*) were also found at localities with high soil P levels. The specis *Sarcococca coriacea* exhibited a positive with RRI value (**Figure 15).**

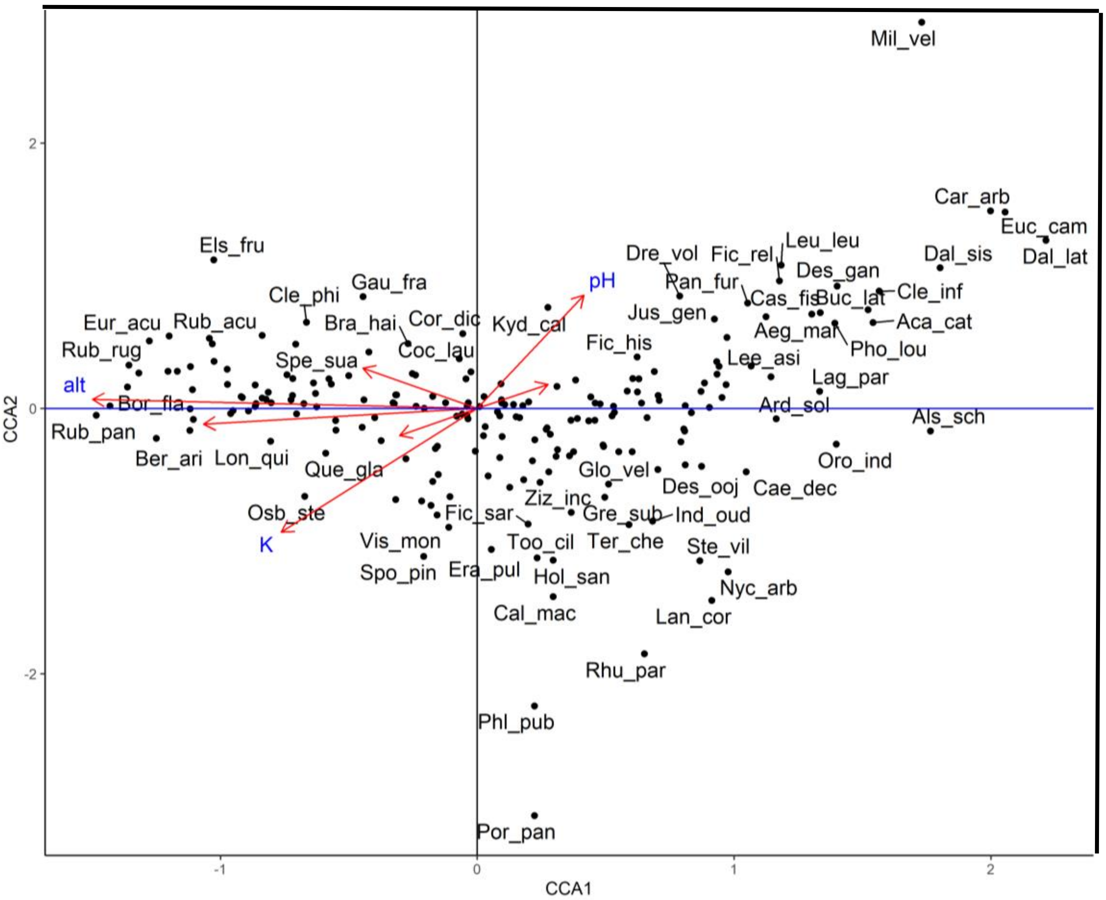


Figure 15: Phanerophyte species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas (axis 1:0.46; axis 2:0.12)

3.4.3.2 The Chamaephytes species

The species score in weighted-averaging ordination techniques (CA, CCA, and DCA) indicates the species centroid or the mode of the unimodal species response curve (ter Braak, 1988). The species scores showed the order of species along the variable. *Roylea cinerea* (r=146) and *Desmodium laxiflorum* (r=1.18) had higher score values in Chameophytes, whereas whereas *Xanthium strumarium* (r=118) got the highest score on the CCA2 axis (**Annex 11**). The stronger unimodal species response curve's mode is represented by species with higher species scores (ter Braak, 1987).

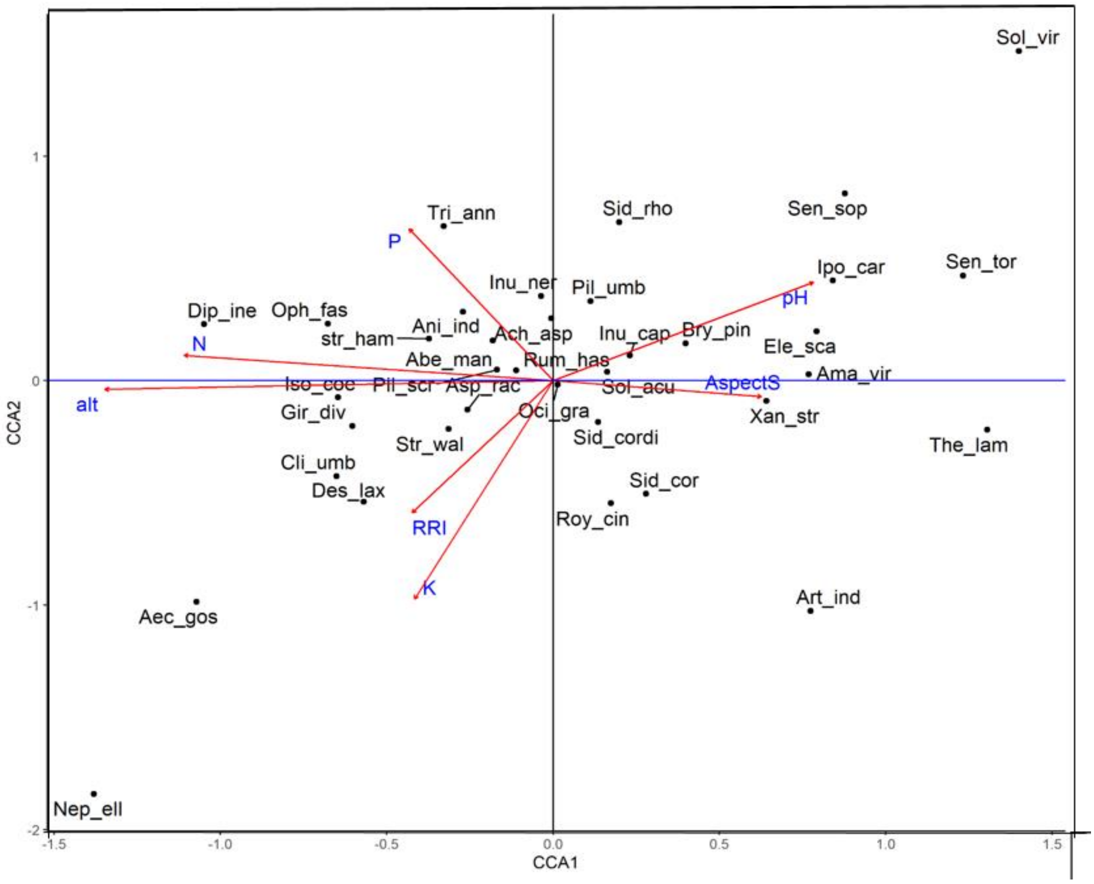


Figure 16: Chamaephyte species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas (axis 1: 0.23; axis 2: 0.15)

In areas with higher nitrogen concentration at high elevations, the species *Desmodium laxiflorum*, *Clinopodium umbrosum*, *Isodon coetsa*, and *Pilea scripta* had high abundances. These species showed negative relationships to soil pH. In areas with greater phosphorus concentration, *Asparagus racemosus* predominated. The species *Aechmanthera gossypina*, *Nepeta elliptica* and *Abelmoschus manihot* also showed high prevalences in soils with higher potassium content. Soil pH was negatively correlated to other explanatory variables (**Figure 16**). At locations with high pH values in the soil, species like *Artemisia indica*, *Ipomoea carnea*, *Solanum virginianum*, and *Thespesia lampas* were more frequently found.

3.4.3.3 Hemicryptophytes species

The Hemicryptophytes species *Panisea demissa* and *Peperomia tetraphylla* obtained the species score 1.76 and 1.46, respectively on CCA1, whereas *Trifolium repens* (r=1.56) and *Eleusine indica* (r=1.37) obtained high scores on CCA2 (**Annex 11**).

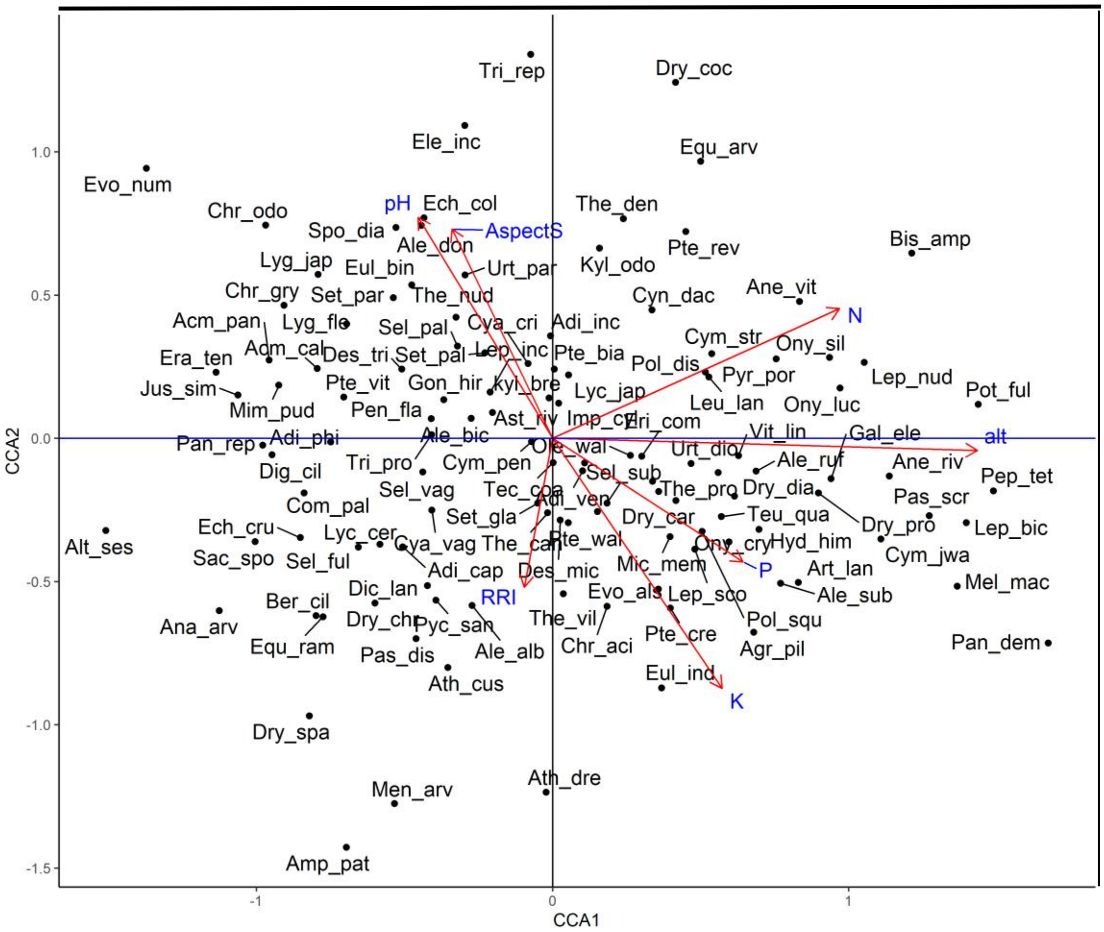


Figure 17: Hemicryptophyte species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas (axis 1:0.28; axis 2:0.14)

Elevation, followed by N, K, and pH, showed the strongest correlations to Hemicryptophyte species. In high N containing sites at higher elevations, the species *Bistorta amplexicaulis, Cymbopogon jwarancusa, Galium elegans, Lepisorus bicolor, Onychium lucidum,* and *Potentilla fulgens* displayed high dominancies. Along with these species, *Drynaria propinqua* and *Drymaria diandra* were also abundant in areas with high P concentrations (**Figure 17**).

In sites with higher soil nitrogen concentrations, the species *Lepisorus nudus*, *Onychium siliculosum*, *Peperomia tetraphylla*, and *Pteridium revolutum* displayed high abundances. The major species of high K-containing locations were *Chrysopogon aciculatus*, *Cymbopogon stracheyi*, *Nephrolepis cordifolia*, and *Thelypteris procera*. The pH value showed the opposite relationship to potassium. The species *Aleuritopteris doniana*, *Echinochloa colonum*, *Eulaliopsis binata*, and *Gonostegia hirta* demonstrated high dominances towards sites of comparatively higher pH as well as at south aspects of hill.

3.4.3.4 Geophyte species

Among the Geophyte species, *Arundina graminifolia* (r=1.48) and *Geranium nepalense* (r=1.24) showed the highest scores on CCA1 whereas *Habenaria dentata* (r=1.37) and *Rhaphidophora glauca* (r=1.20) had the highst scores on CCA2 axis (**Annex 11**).

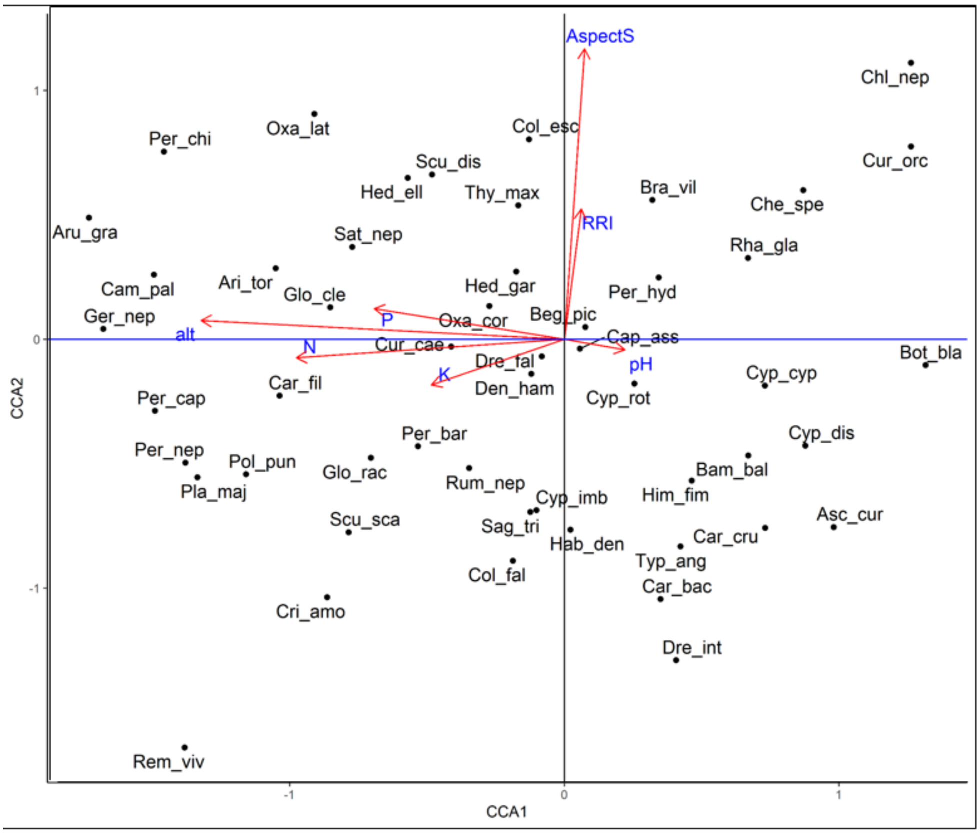


Figure 18: Geophyte species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas (axis 1:0.23; axis 2:0.09)

The species *Geranium nepalense, Persicaria capitata, Plantago major, Rumex nepalensis* and *Satyrium nepalense* exhibited the highest frequency at high N containing sites at higher elevations. The species *Thysanolaena maxima* and *Scutellaria scandens* were more prevalent in areas with higher potassium concentrations. The species related to Geophytes: *Carex cruciata, Globba clerkei, Globba racemosa, Hedychium ellipticum, Oxalis latifolia,* and *Remusatia vivipara* all exhibited higher dominancy at locations with higher soil phosphorus levels (**Figure 18**). At locations with higher pH content, species like *Cheilocostus speciosus, Curculigo orchioides, Hedychium gardnerianum*, and *Typha angustifolia* were more prevalent.

3.4.3.5 Therophytes species

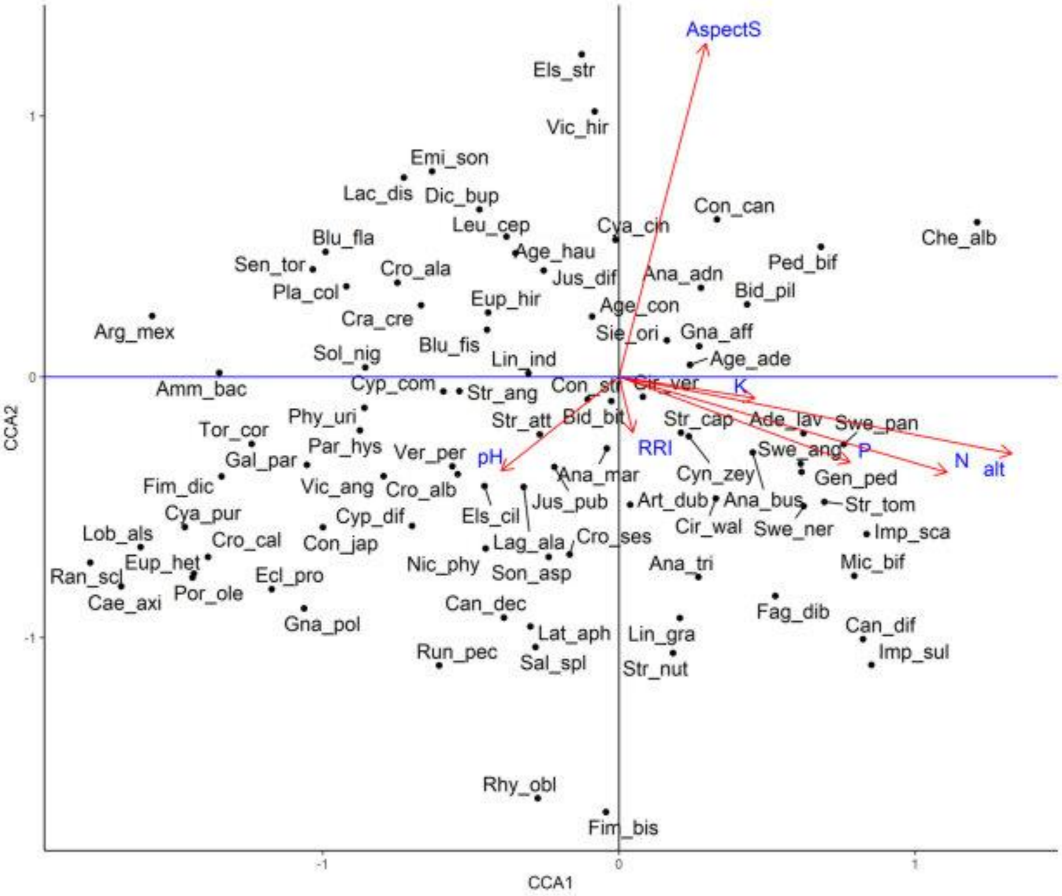


Figure 19: Therophyte species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas (axis 1:0.20; axis 2:0.10)

The Therophytes species *Impatiens sulcate* (r=1.13) and *Chenopodium album* (r=1.08) had the greatest score in CCA1, whereas *Galinsoga parviflora* (r=2.38) and *Rhynchoglossum obliquum* (r=1.93) had the higher score in CCA2. In areas with higher levels of N and K at higher elevations, the species *Chenopodium album, Fagopyrum dibotrys, Impatiens scabrida, Impatiens sulcata, Lindenbergia grandiflora, Pedicularis bifida, Swertia angustifolia,* and *Swertia paniculata* demonstrated higher dominance (**Figure 19).** The species *Anaphalis triplinervis, Lathyrus aphaca, Rhynchoglossum obliquum,* and *Strobilanthes capitata* also tended to occur more abundantly at high P-containing areas. Soil pH showed the opposite relationship with elevation, N and K. The majority of the therophyte species, including *Galinsoga parviflora, Blumea fistulosa, Crotalaria albida, Gnaphalium polycaulon* and *Lindenbergia indica* exhibited greater dominance at places with higher pH levels, demonstrating a favorable association between pH and plant growth.

With regard to Geophytes, and Therophytes on the CCA2 axis, the slope aspect to the south showed a sizable positive association, while the slope aspect to the north showed a sizable negative relationship (**Annex 11**). The pH often correlated positively with the south aspect for Chamaephytes, and Hemicryptophytes, but negatively for Therophytes. RRI and south aspect have been discovered to have a beneficial relationship in Geophytes (**Figure 15-19**). According to overall result, the environmental factors showed the variable response to the overall species composition as well as individual life form species composition.

3.5 Discussion

3.5.1 Elevational species richness pattern

The association between species abundance and elevation was confirmed by the regression analyses. The outcomes demonstrated that species richness shapes of individulal life forms and total vascular plants show distinctive unimodal patterns with respect to elevation. The Gaussin shaped patterns of alpha diversity for Chamaephytes and Phanerophytes species with elevation showed the stronger significant relationships than other life forms. This type of finding was also found in reseach works of Bhattarai & Vetaas (2003); Bhattarai *et al.* (2004); Bhatta & Chaudhary (2009); Bhattarai *et al*. (2014); Subedi *et al*. (2015); Bhatta *et al.* (2018); and Nepali *et al.* (2020). Similar outcomes were also reported in various studies from outside Nepal, such as: on Mount Kinabalu, Borneo (Grytnes & Beaman, 2006); Baekdudaegan Mountains, South Korea (Lee *et al.,* 2012); Laddakh, India (Namgail *et al*., 2012); Gyirong Valley, Central Himalaya (Hu *et al*., 2017); Mt. Namjagbarwa region

(Eastern Himalayas), China (Sun *et al*., 2020). Because of this, the result of this work supports the proposed hypothesis.

The stations (also known as the data points) must be fairly evenly distributed across the overall gradient in order to conduct correct descriptive statistical evaluates of the variation of species richness with altitude (Rahbek, 1995). The elevation range of both aspect in study area was not similar. So, the species richeness present in equal elevation range in both aspects (south and north) was also applied for regression, which showed the insignificant linear decreasing pattern against elevation. The Some previous research works also reported the monotonic increasing structure in ferns (Desalegn & Beierkuhnlein, 2010), in hemicryptophytes and chamaephytes (Mahdavi *et al.,* 2013), but monotonic decrease in all plant species (Zhang *et al*., 2016), in woody plants (Cirimwami *et al.,* 2019) and in animals (Lee *et al.*, 2021) with elevation. After noticing a monotonic decline with woody species and incline with herbaceous life forms with elevation, Cirimwami *et al.* (2019) assumed the presence of distinct eco-physiological characteristics affecting to each plant life-form as well as the formation of life form-specific elevation configurations.

Elevation is a complicated mix of topographical and climatic variables (Stevens, 1992), which influence on qualities of soil (Polis, 1991; Mahdavi *et al*., 2013) in addition to distribution of species (Thorne *et al.,* 2022). The elevational abundance rise is prejudiced by many courses, with environmental features and evolutionary history (Sun *et al.*, 2020). Various factors have been found to be contribute to a hump shaped pattern: mid-domain effect (Lee *et al.,* 2012), climate (Liang *et al.,* 2020), the joint effects of climate and struggle (Wang *et al.*, 2018), and edge effects (Shrestha & Vetaas, 2009). Single key factor can not describe all species abundance patterns ((Hu *et al.,* 2017). The mid-domain outcome is caused by the overlap of species from two or more communities. At 1300–1400 m in the area of this study, the overlap in species richness between a S*horea robusta* forest and a *Schima–Castanpopsis* forest may contribute to the edge effect between the two forest communities, which may cause a hump-shaped species richness structure.

Therefore, elevation significantly influences the development of unimodal shapes in the scattering of species by changing other parameters directly or indirectly in mountainous region. This unimodal pattern is favourable for species of long elevation range, but it may not be suitable in short elevation range.

3.5.2 Species richness- environment relationship

The correlation result show that environmental factors: altitude and soil nitrogen are significantly negatively linked with hemicryptophytes, therophytes, and total vascular species richness. Similar result was also reported by Han *et al.* (2022) between species richness, soil nitrogen, and soil moisture content along elevation gradient. But, Ohdo & Takahashi (2020) reported the positively correlation of elevation and soil nitrogen availability with the diversity of trees and fern species.

On this result, soil P shows statistically positive relationship with geophyte richness but negative relationship with total species richness. In opposite to this result, Wang *et al*. (2007) also found the undesirable relation of available soil N and P with plant diversity in alpine meadows. Different ecosystem components exhibit different patterns of plant and soil minerals status throughout altitudinal gradients in mountain (He *et al*., 2016). This concludes that the elevation and soil nitrogen are main influencing factor which exhibit a noticeable negative association with total vascular species and the majority of the life form species exhibit a noticeable negative association with elevation and nitrogen when compared to other factors.

3.5.3 The Relationship of Species Composition with Environment

It is challenging to understand the intricate relationships that exist between flora, soil, and topography. According to the ordination results, only around 5% of an inertia value of life forms can be described by constrained factors, whereas 95% of the variation cannot be explained by the present variables. Several factors affect the occurrence as well as the distribution of species. The interactions between abiotic and biotic variables influence the distribution of species either cooperatively, competitively, or independently of one another (Mott, 2010; Yilmaz *et al.,* 2017) or also influence on the specific geographical distribution and habitat relationship of species (Rodríguez *et al*., 2018). Ordination analysis helps for strong optimization of complications affected by parametric uncertainties in species distribution (Rehman & Langelaar, 2015). According to this study, unconstrained factors (the variable which are not used in this analysis) affect species distribution more significantly than constrained variables. This leads to the conclusion that the presence of many unconstrained factors and their interactions determine the existence and scattering of species in any given region. The association between a species and its surroundings is hazy and very intricate from an ecophysiological perspective.

The CCA ordination confirmed that a number of environmental factors significantly affected the plant life-form species composition. According to the ordination results, hemicryptophytes, phanerophytes, and therophytes have strong positive relationships with elevation and soil nitrogen, but chamaephytes and geophytes have substantial negative relationships. Elevation showed a stronger relationship with life form species than the other variables included. It was supported by positive relation of phanerophytes in the semi-arid valley of Zapotitlan, Mexico (Pavon *et al*., 2000) and partially supported by positive relation of Hemicryptophytes and chamaephytes with elevation (Cordeiro & Neri, 2018). Due to variations in temperature and water availability, elevation clearly has a key role in regulating species composition by resulting in a range of habitats (Korner, 2000). The positive relation with soil nitrogen is supported by linear relation of nitrogen and elevation. Nitrogen is needed to make different forms of protein but its absence has a detrimental effect on plant development. The availability of nitrogen in the soil, which varied with elevation, is the main soil characteristic impacting the composition and variety of plant species (Han *et al.,* 2022). The variety and composition of plant societies present on nutrient-poor soils are more affected by climatic variation than plants present on nutrient-rich soils (Shovan *et al.,* 2020). This summarizes that N has the similar life specific response as elevation and many plants like: *Desmodium laxiflorum, Pedicularis biflora*, and exhibit high abundance at high N-containing soil areas. The relation of available N and P with soil organic matter content, and were found closely but negatively to plant diversity (Wang *et al.*, 2007).

The Phanerophytes, Chamaephytes and Hemicryptopytes show the strong negative relationship with K of soil. Potassium has a significant impact on a plant's metabolism and is necessary for nutrient uptake (Sustr *et al*., 2019), photosynthesis (Zahoor *et al*., 2017), drought tolerance, enhanced winter hardiness (Anschutz *et al*., 2014), cellular growth, wood formation and protein synthesis. At the level of the individual plant, K+ plays a physiological-metabolic role that includes internal material and energy transfer as well as an improvement in plants' ability to respond to abiotic and biotic stimuli (Sardans & Peñuelas, 2021)**.** A small part (0.1–0.2%) of the total soil K+ is made up of K ions in soil solution, which is freely obtainable to plants (Britzke ***et al*.,** 2012) and plant K^+ uptake seems to be connected with water accessibility (Sardans *et al*., 2012).

It is clear that different plant species react differently to pH because of the statistically positive significant association between Phanerophytes, Chamaephytes, and Hemicryptophytes in different CCA axes. Similar significantly positive correlation of soil pH with species richness is also reported (Gough *et al.,* 2000; Schuster & Diekmann, 2003). The pH also showed a unimodal response with the plant species diversity and peaked at a pH of around 6.5 in central Bohemia, the Czech Republic (Merunková *et al.,* 2014). The pH-species association is influenced by variations in soil precipitation because the influence of soil pH on species abundance is typically smaller than the impact of precipitation (Palpurina *et al.,* 2016). Usually, soil pH 6.0-7.5 is suitable for most plants because most nutrients become accessible to plants in this pH range (McCauley *et al*., 2017). It effects on plant nutrition, nutrient driving and soil remediation that have an impact on plant development and biomass production (Neina, 2019). So**,** being as master element, pH shows variable effects (either positive or negative) on plant growth and their distribution along with other variables.

Elevation demonstrates a statistically significant relationship with all life form species composition. The presence of a positive association between elevation and species composition of Hemicryptophytes, Phanerophytes and Therophytes (canonical correlation $r > 0.88$; $p < 0.05$) and adverse association between elevation and Chamaephytes and Geophytes demonstrates the specificity of relationships of plant life form with elevation. Elevation has a stronger correlation to species composition than with species richness. Ecological and evolutionary responses of biota are a reflection of the differences in edaphic, climatic, and other variables along altitudinal gradients. Due to presence of different concentration on soil along an elevational gradient, other soil elements exhibit varying connections.

Similarly, the affirmative effect of south aspect and negative result of north aspect on same life forms: geophytes and therophytes indicates that the effect of slope aspect is plant specific. It was also supported by previous researches: Nepali *et al.* (2021). The slope side and slope location have little impact on plant assemblage but have a significant impact on plant variety and spatial dispersion (Zeng *et al.,* 2014). More moisture in the north-facing woods can result in improved plant yields and good regeneration potential, whilst modest litter accumulation in the south-facing forests can aid in natural regeneration (Maren *et al.,* 2015). The slope aspect presented a substantial outcome on species structure, but not on species richness. The combined influences of topographical variation, climatic conditions, slope aspect, and other elements determine the features of a forest stand. Respectable soil situations may supply plants with sufficient nutrients and water, and topographic features (such as elevation and slope aspect) are directly related to local climate, which has a significant impact on plants (Davies *et al.,* 2007).

By comparing the correlation coefficient value and canonical correlation coefficient value, it can be concluded that the environmental factor shows the stronger relation with species composition than species richness. The consequence of environmental factors on species structure is relatively simpler to research than the influence of variables on species richness. The species richness displayed a unimodal organization with altitude. The slope aspect presented a substantial influence on species conformation, but not on species richness

Out of the tested environmental variables, elevation showed the strongest significant relation with composition of overall vascular species and individual growth form composition. On the basis of responses with life-form species richness and their alignment, the impact of environmental variables is, in order of declining importance: Elevation > Nitrogen > Potassium > pH > Aspect > RRI.

The altitude had a considerable influence on the types of soil and their processes, according to Baumler & Zech's (1994) investigation of the chemical and mineralogical composition of soil in eastern Nepal. Plant communities are dynamic systems that are always changing due to local extinction and immigration. So, species composition can overlook crucial ecological processes including immigration and extinction as well as within-patch environmental heterogeneity (Morris *et al.,* 2014). The species compostiton as a response variable is clearly beneficial for studies of landscape ecology and biogeography than species richness (Aggemyr *et al.,* 2018). Therefore, plant community structure should be used as a reliable and instructive indicator for biogeography study and conservation design.

3.6 Conclusions

This in-depth ecological research demonstrates the relations between diversity within Raunkier's plant-life forms (Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes and Therophytes) distributed in the Arghakhanchi district and adjoining areas with some environmental variables (elevation, RRI, soil pH, nitrogen, phosphorus, potassium and aspect). This investigation demonstrated that a unimodal pattern with respect to elevation was followed by all life forms and total vascular species. Although the associations were life form specific. The explanatory variables revealed stronger connections with species composition than with species richness. The plant life forms: Phanerophytes, Hemicryptophytes, and Therophytes exhibited the statistically significant positive relationship, but the Chamaephytes and Geophytes revealed the negative correlation with elevation as well as soil nitrogen. Following this finding, Phanerophytes, Chamaephytes and Hemicryptophytes had a negative connection with potassium. In conclusion, the environmental deviations brought about by elevational gradients had a significant impact on topography, soil composition and climate, resulting in the spatial distributions of the variety of the plant communities in mountainous locations.

4. LICHEN DIVERSITY AND ITS RELATION WITH ENVIRONMENT

4.1 Introduction

Lichen is a cooperative link between mycobiant (fungal partner) and phycobiant (algal partner) and function as useful bio-indicators for assessing the effects of anthropogenic actions, which are transforming the bionetworks of the world (Ardelean *et al*., 2015). The majority of lichen species are found in decaying wood, rocks, soil, and tree and shrub bark in less polluted environments, from tropical riverine forests near the equator to alpine region. The variety and richness of epiphytic lichen are strongly correlated with host tree type (Roper, 2018). An aged or stressed tree's bark may become more fragile, with more fissures and uneven surfaces that make it easier for lichens to adhere. Age-related variations in bark's chemistry, texture, and capacity for holding water have an impact on the kinds of lichen that can survive there (Daniel, 2013). Lichens are thought to cover 6-8% of Earth's terrestrial surface (Asplund & Wardle, 2016).

Baniya *et al.* (2010) reported 525 lichen species are distributed between 200 to 7400 m in which 55 were endemic to Nepal. In the lichen species reported, crustose, foliose and fruticose thallus form occupy 39%, 44% and 17 % respectively (Baniya & Bhatta, 2021). All lichen growth forms displayed a unimodal association with elevation, with crustose lichens reaching their peak at 4100–4200 meters above sea level, foliose lichens peaking at 2400–2500 meters, and fruticose lichens reaching 3200 meters (Baniya *et al*., 2010).

Lichen dispersal is considerably exaggerated by substrate types that were reliant on land use types as well as tree canopy (Chongbang *et al.,* 2018). The lichen species abundance and richness of particular growth forms, specific substrate forms and definite photobiont types, except wealth of terricolous lichens, leprose, muscicolous displayed a unimodal association with altitude (Grytnes *et al*., 2006; Baniya *et al*., 2010). The richness of lichen species might be reacting to the forest trees' shade (Grytnes *et al*., 2006)

The safeguarding of any group of creatures wants elementary data on dissemination diversity and dynamics (Dietrich & Scheidegger, 1997). Lichens exhibit more distinct patterns of species variety related to territory change than other groups of plants at the same places (Jonsson & Jonsell, 1999). The spread of lichen is influenced by macroclimatic variables: rainfall and temperature and microclimatic factors such as shadow and humidity and substrate like as bark type, surface corrugation and age, moistness holding, pH, and nutrient status (Wolessley & Aguirre-Hudson, 1997). Numerous crustose lichens are sensitive to environmental changes, slow-growing, long-living indicators of ecological continuity (Seaward, 1982; Rose, 1992). According to Chongbang *et al.* (2018), the dissemination of lichen species is greatly influenced by substrate forms that depend on the types of land uses as well as canopy condition. The environmental factors were connected to the difference in species composition (Rose, 1976).

Lichen are a crucial species in many ecosystems. For a range of animals, such as deer, birds, and rodents, they serve as food sources, habitats, and sources of nesting materials. They protect plants and rocks from severe weather including snow, wind, and rain. Same environment may response differently to different group of species. It was supported by result of Zuijlen *et al.* (2020), on the same environmental gradient, vascular plants, lichens, and bryophytes respond in different ways.

The previous studies shows that lichen distribution depends of nature of forest type as well as chemisty of substratum in any area. Due to increasing human migration in the Terai region and increased landslides and deforestation in the Churia Hills, habitat change is more prevalent there. So, exploring lichen species and their host species present in lowland areas is important for their conservation and other reasons. Lichen species can be found in good numbers on the bark of higher plants. Therefore, the existence of lichen species may be encouraged by higher plants. The variety of lichens present in Nepal's tropical and subtropical regions has received little attention up to now. The main objective of this unit is identify the lichen species present in study area and to show the relationship with environmental factors.

4.2 Literature Review

4.2.1 Lichen studies in outsides of Nepal

Theophrastus, at time of 300 BC, first defined as lichen is a part of plant group and coined the term ‘lichen’ (Nayaka, 2014). Lichen word comes from the Ancient Greek Λειχήν (leikhe¯n) and it was the first recorded by Theophrastus in 300 B.E. (Richardson, 1974). Early Devonian (approximately 400 million years old) fossil lichen from the Rhynie Chert, near Aberdeen, Scotland, is the oldest known fossil lichen (Taylor *et al.*, 1995).

According to research of Dietrich & Scheidegger (1997), the proportion of crustose and reproductive lichens decreased with every elevational step, increased in fruticose and vegetative lichens, and was the similar in foliose species.

In order to assess the impact of substrate superiority (branch characteristics) on arrangements of lichen biomass, Esseen *et al.* (1996) matched biomass and species arrangement of canopy lichens on Norway spruce (*Picea abies*) in old-growth and achieved stands in northern Sweden. According to their findings, there were significant limitations restricting the quantity of epiphytic lichens in managed forests, including the insufficient amount of substrate accessible to lichens and young branches, which provide a brief window for lichen establishment and progress. Epiphytic lichen mass was found drastically reduced as old-growth forest is transformed into young, managed stands.

Roper (2018) study on lichens in the upper peninsula of Michigan revealed that there was little to no correlation between lichen diversity and abundance and proximity to lakes, but that there were notable changes between conifer and deciduous species in terms of lichen variety and coverage. Lichens on deciduous trees had a mean diversity and coverage of 23.67% and 4.61 species, respectively, while lichens on conifers had a cover of 7.73% and 3.15 species, respectively. The results revealed a robust association between epiphytic lichen variety and host species.

According to the lichen study on Kashmir, Uttarakhand and Sikkim by Nanda *et al.* (2021), the most of the lichen group species presented the gaussin elevation pattern. The involvement of turnover of β-diversity was larger than nestedness at all sites. Beta diversity and its constituents of turnover and nestedness varied meaningfully with altitude. While species turnover enlarged considerably along the altitude, nestedness dwindled meaningfully in Kashmir and Sikkim but increased considerably in the Uttarakhand. The research in the Himalayas, conveys out that macrolichen species abundance, β-diversity, and its constituents of turnover and nestedness differ along the altitudinal ascents across the Himalayan range.

4.2.2 Lichen studies in Nepal

Lichen flora is less commonly known at local level in Nepal as in many other countries. So, exploration of lichen was initiated in Nepal by foreign scientists after Nepal opened entry for foreigners (Baniya & Bhatta, 2021). On the basis of the collection of Sir Joseph Dalton Hooker and Thomson, Nylander published on article named as "*Synopsis Methodica Lichenum*" in 1860, which was first publication related to lichen. Similarly, the 31 species of lichen collected by Sommervella (1924) from Mt Everest region described by Paulson in 1925 (Obermayer & Poeltj, 1992).

The Indian lichenologist Awasthi (1957) reported 38 species of lichen with new species *Cetraria nepalensis, Cetraria pallida* and *Physcia melanotricha* from east Nepal based on his own collection. J. J. Poelt, an Austrian lichenologist, led several lichen trips to Nepal in 1962, including ones to the Langtang region and the southern face of Mount Everest, discovering 39 new taxa for science (Baniya, 2021).

Asahina & Kurokawa (1966) reported 133 species including 62 new lichens species from eastern Nepal. Similarly, Kurokawa (1967) counted 53 lichen species from Rolwaling region in which 26 species were new to Nepal. He also described 38 species (*Parmelia*- 24 species and *Anaptychia*-14 species) from Kathmandu valley in 1988. Similarly, Sharma & Kurokawa (1990) informed 10 species of *Anaphychia* and 21 species of *Parmelia* from Nepal. Similarly, Esslinger & Poelt (1991) listed the 280 species of lichen and declared that the elevation of lichen species ranges from about 3000m to 5100m in Langtang and Khumbu region.

Individual work of Nepali scientists is adding bricks in lichen exploration of Nepal. Baniya (1996) found 99 taxa of lichens from Shivapuri and Sikles, Kaski, in which 33 lichen species were new to Nepal. Similarly, Pathak (1998) counted 52 lichen species from Hetauda and Dang. Devkota (1999) studied the antibiotic properties of *Heterodermia diademata*, *Parmelia nepalensis* and *Parmelia reticulata*, out of total collected 55 lichen species from Namobuddha, Kavre. .

Baniya & Gupta (2002) reported the 77 species of lichens related to 25 families and 28 genera from 2,900 to 3,400 m in Thodimai of Annapurna conservation area and 78 lichen species related to 17 genera and 15 families between 1,100 - 2,300 m from Arun River Bridge to Tashigaun of Makalu-Barun National Park respectively.

Baral (2015) reported 68 species and 13 species of lichen from Sagarmatha National Park and Manaslu Conservation Area respectively. Rai *et al.* (2017) reported 28 new species belonging to 13 families from the community forest of Dadeldhura districts. In the Ghunsa valley of the Kanchenjunga Conservation Area, Eastern Nepal, from 2200 m to 3800 m, Chongbang *et al.* (2018) recorded the 229 lichen species related to 71 genera from four types of land-uses: cultivated land, meadows, exploited, and natural forests.

In Kathmandu, the distribution of corticolous lichen was investigated by Karmacharya *et al.* (2022). They found 97 species of corticolous lichens related to 21 families and 44 genera. There were more lichen species in untouched areas than in disturbed areas, and their findings support the idea that pollution levels have a significant impact on lichen species.

According to previous researches, greater lichen diversity was collected by exploited forests with less open canopy than open meadows and cultivated regions. There was a noticeable steady rise in the diversity of lichen types from cultivated land to forests. Up until now, sites in high elevational regions have received more attention from lichen researchers than low Himalayan regions. The association between ecological conditions and the makeup of lichens has also received little research.

4.3 Material and Methods

4.3.1. Lichen sample collection

The lichen species were generally remains attached on tree and shrub trunks or stem, rocks and soil wall. The same sampled plot from which vascular plants were gathered also used for collection of lichen. The crustose, foliose and fruticose lichen which are attached below 10 feet on stem barks as well as rocks and soil wall were separated from substratum with the help of knife. The collected lichen samples were stored separately in small plastic packs, sealed and carried into laboratory for further identification.

4.3.2 Lichen identification

The chemical analysis is the best method of lichen identification. But, due to financial shortage and unavailability of laboratory in Nepal, all the lichen samples were identified by comparing with already identified species specimens present in KATH laboratory, Godavari and with the help of the appropriate sources and checklists (Awasthi 1991; Sharma 1995; Awasthi 2007; Singh & Sinha 2010).

4.3.2.1 Morphological and Anatomical test

Under a stereomicroscope, the morphological traits of the lichen specimens were examined. A compound microscope with a magnification range of 10 to 40 times was used to study the anatomical studies of lichen thallus and fruiting bodies. By creating slides, anatomical structures were investigated. The lichen samples were stained with cotton blue and mounted in a 5% solution of potassium hydroxide (KOH) (Nayaka, 2005). The prepared slides were studied under the compound microscope.

4.3.2.2 Color Reaction

With the application of particular chemicals, known as a color reaction, the lichen thallus displays its distinctive color. This is crucial for correctly identifying lichens. Three chemical reagents are used to identify lichens: I aqueous potassium hydroxide (KOH); (ii) bleaching powder or aqueous calcium hypochlorite solution ($CaOCl_2$); (iii) aqueous solution of p-phenylenediamine; and ethanol. In addition, HNO3, Lactophenol, Cotton Blue were also used in required case (Nayaka, 2005).

All the above procedures were applied on each of the lichen thallus at the laboratory of the Department of Botany, Butwal Multiple Campus, Butwal, Nepal. Some difficult lichen specimens (Appendix II) were examined by thin-layer chromatography (TLC) run in solvent A.

4.3.3 Statistical analysis

4.3.3.1 Data management

The relative humidity records of three 3 climatic stations of study region was obtained from Department of Hydrology and Meteorology. These data was regressed to change in humidity per 100 m contour elevation**.**

Similarly, the lichen species present in individual quadrats of all stud area was collected according to the forest types. The numerical data of lichen species of individual forest and elevational range of such forest type as well as the type of forest were used in statistical analysis.

4.3.3.2 Statistical methods

Excel and R tools were used to examine the acquired data. Regression *GLM* method was also used to demonstrate the association of lichen species with elevation. The 'Vegan' and 'Venn Diagram package: R version 4.3.1 (2023) used to display the relationship between habitat type and species

4.4 Results

4.4.1 Lichen diversity

Lichen, a symbiotic relationship between mycobiant (fungal partner) and phycobiant (algal partner) functions as biological indicator for pollution and thallus remains attached on bark of trees, rocks, wall etc. This study showed that the species richness as appearance of alpha diversity totals 47 species related to 17 genera and 10 families found in study area (**Figure 20**). Among the lichen species, Parmeliaceae was reported as the largest family (8 genera and 23 species). It was followed by Physciaceae, Cladoniaceae and Ramalinaceae (**Figure 20**).

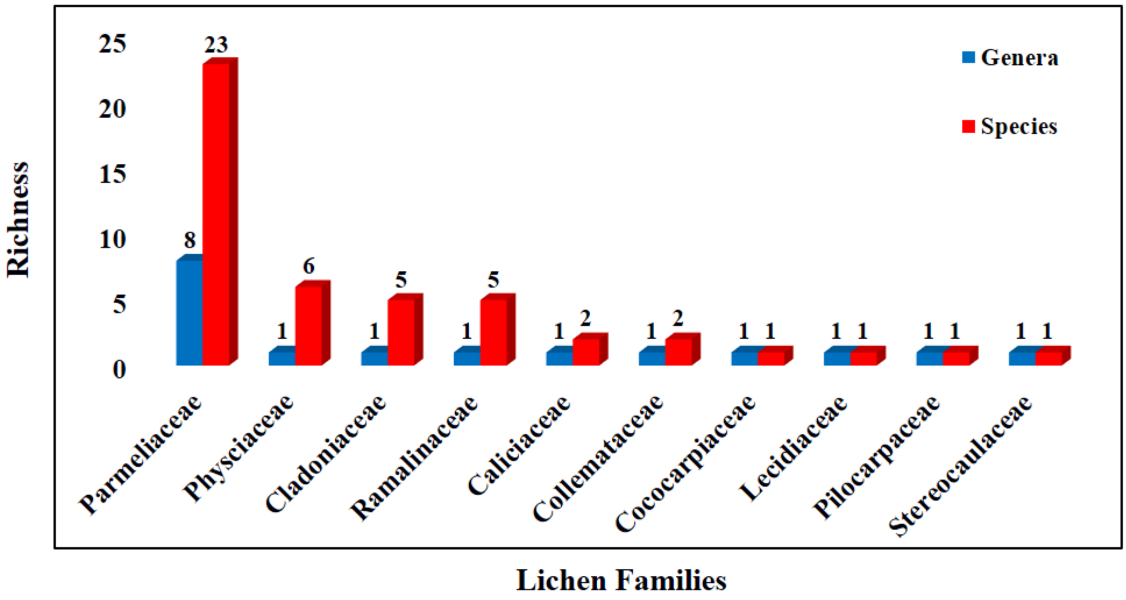


Figure 20: The lichen diversity with their included families, genera and species

Among the lichen genera, *Parmotrema* and *Heterodermia*, were the largest genera bearing 7 and 6 species respectively. They were followed by *Cladonia*, *Ramalina*, *Usnea* genera (**Annex 12**).

Foliose lichen, which has 30 species belonging to 6 families and 11 genera, demonstrated a vast diversity based on its thallus morphology. (**Figure 21 A).** Based on ecological regions, crustose showed the decreasing pattern from tropical to temperate, but foliose varieties of lichen were prevalent in all 3 regions (**Figure 21 B**).

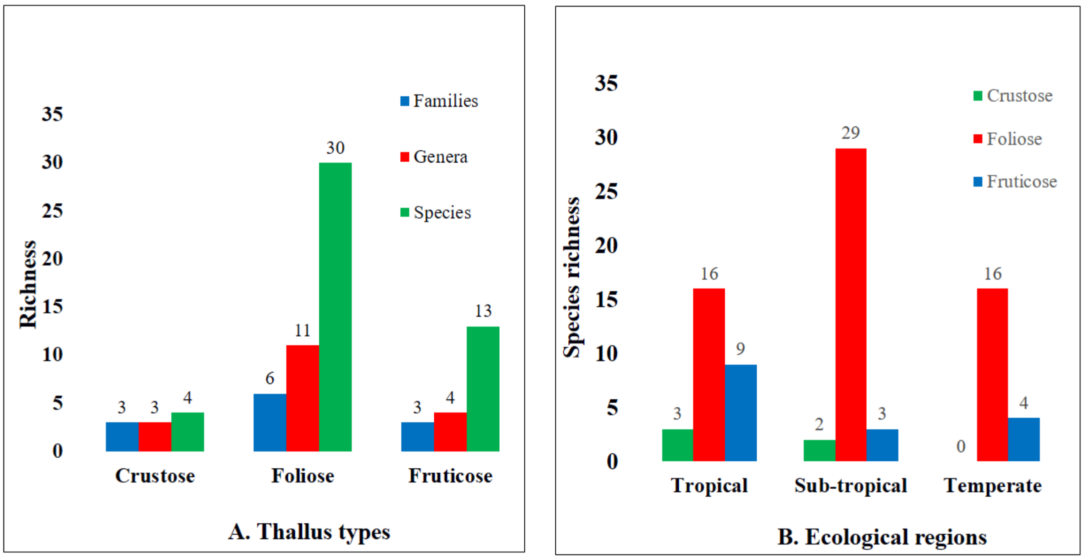


Figure 21: Lichen diversity on the basis of (A) Thallus forms, and (B) Ecological regions

4.4.2 Lichen diversity on the basis of habitat

On the lichen species, found on the barks of tree and shrub species, wood, as well as on rocks or soil, they were classified into corticolous, lignicolous, saxicolous and terricolous respectively (Awasthi, 2007).

Corticolous lichen has the highest species richness, with 30 species spread across 5 families and 13 genera (**Figure 22** and **Annex 12**). The lichen diversity was found the highest (39 species) in *Shorea_Schima_Pinus* forest and the lowest (14 species) in soil or rock (**Figure 23).**

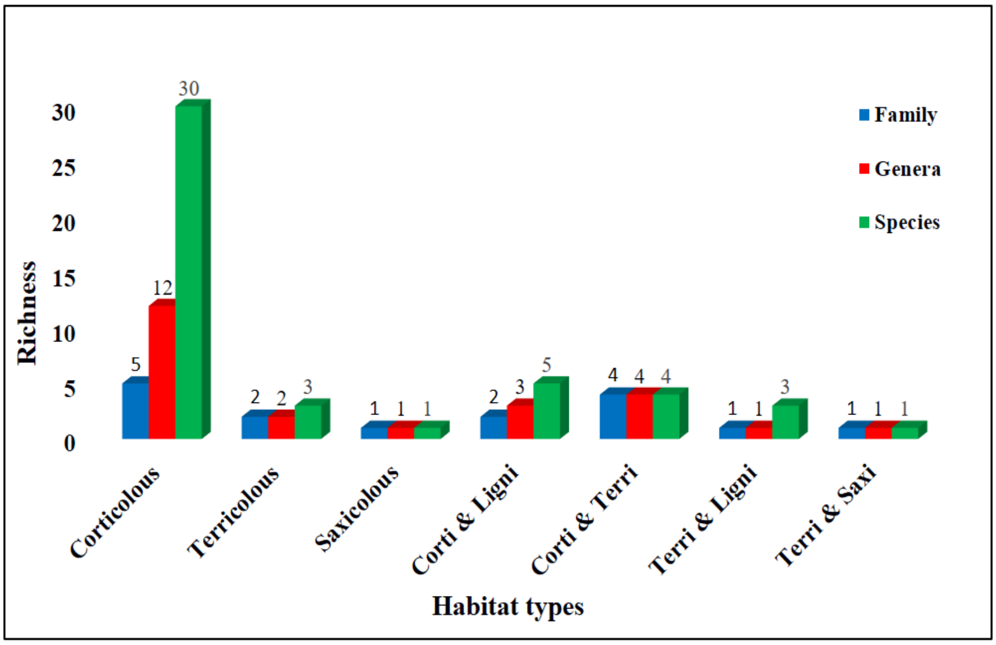


Figure 22: Lichen diversity on the basis of habitat types

Corticolous lichen has the highest species richness, with 30 species spread across 5 families and 13 genera (**Figure 22** and **Annex 12**). The lichen diversity was found the highest (39 species) in *Shorea_Schima_Pinus* forest and the lowest (14 species) in soil or rock (**Figure 23).** The species: *Parmelinella wallichiana* and *Septotrapelia usnica* were found in all habitats (**Annex 12**).

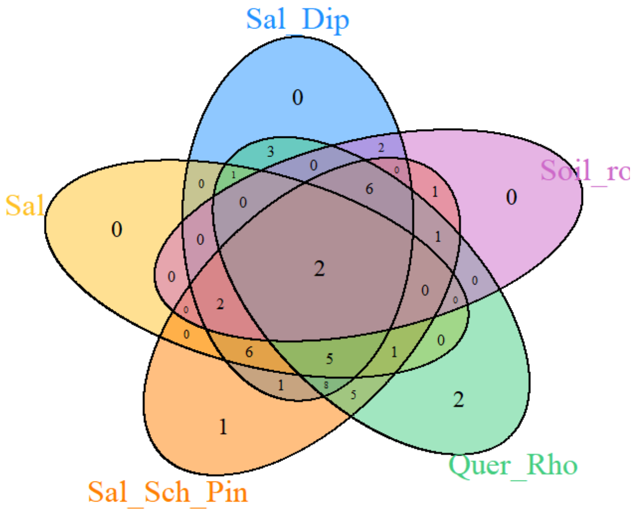


Figure 23: Venn diagdram to show lichen diversity present on different habitat types

4.4.3. The elevational pattern of lichen species

The lichen species present in 100 m contour elevation of study area regressed by use of *GLM* method. The whole lichen species abundance increased continuously when the elevation increased and above than 1500 meter the richness started to decrease following the statistically substantial (R^2=0.83 & $p < 0.05$) unimodal structure with elevation (**Figure 24. D**).

Although the peak elevation value was discovered to be variable, the individual thallus form lichen species also revealed the statistically significant unimodal pattern with elevation. The crustose, foliose and fruticose lichen species showed the maximum species at 800 m (**Figure 24. A**), 1600 m (**Figure 24.B**) and 1500 m (**Figure 24.C**) respectively.

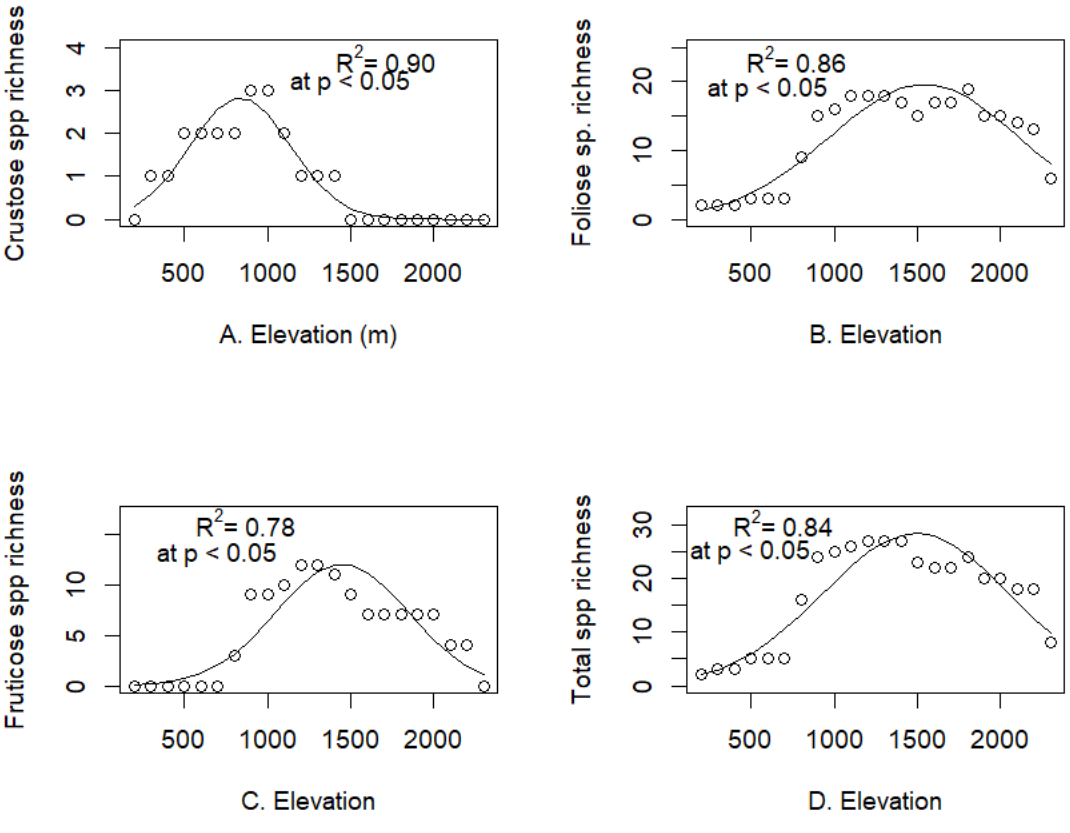


Figure 24: The regression result of (A) Crustose lichen, (B) Foliose lichen, (C) fruticose lichen and (D) total lichen species against elevation

4.4.4 Lichen-host species relationship

Most of the lichen species show epiphytic nature on host species (mainly tree and shrub species). The host tree species of this study area are; *Shorea robusta*, *Castanopsis indica, Schima wallichii, Syzygium cumini, Terminalia tomentosa, Wendlandia coriacea, Ficus benghalensis, Falconeria insignis, Lyonia ovalifolia* and shrub species like: *Buddleja asiatica, Osyris wightiana, Melastoma malabathricum* etc.

The richness of lichen species with tree and shrub species was tested by Tukey HSD test. It showed that there was significant different of lichen richness with both tree and shrub species. But, no significant different appeared between tree and shrub species (**Figure 25**).

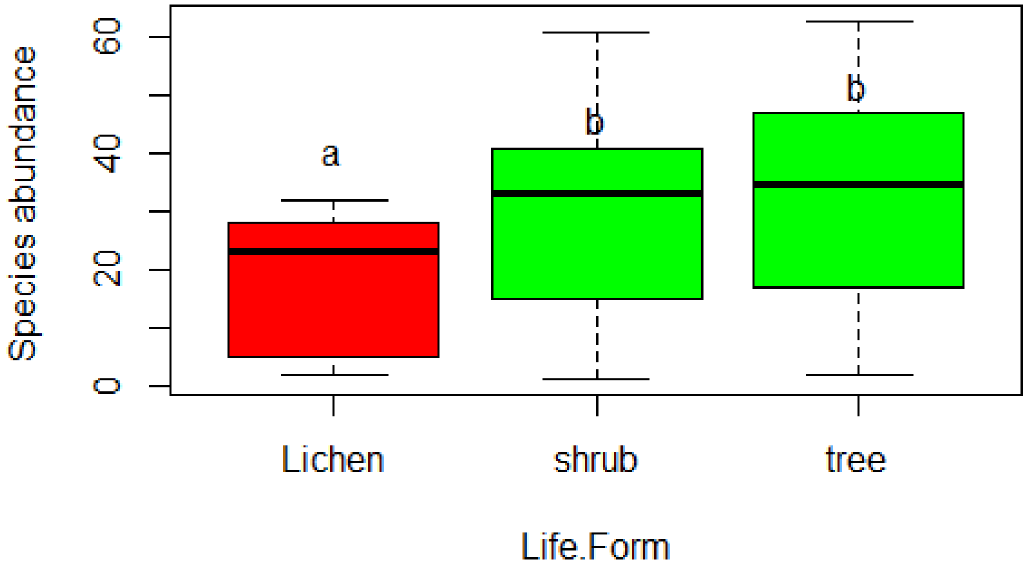


Figure 25: The Tukey HSD test between lichen species and tree and shrub species

GLM regression applied to show the elevation patten of lichen and host species richness. The lichen species and host life form species (trees and shrubs) both exhibited a statistically significant unimodal relationship with elevation. However, they have a variety of elevations where they may get the most species (**Figure 26 A**). At 1300 meters, tree and shrub species reached their apex, whereas lichen reached its high at 1500 meters.

Similarly, the lichen richness also regressed against the woody species richness. As a result, the lichen species displayed a statistically significant linear structure with host species richness ($R^2 = 0.60$ at *p 0.05*) (**Figure 26 B**).

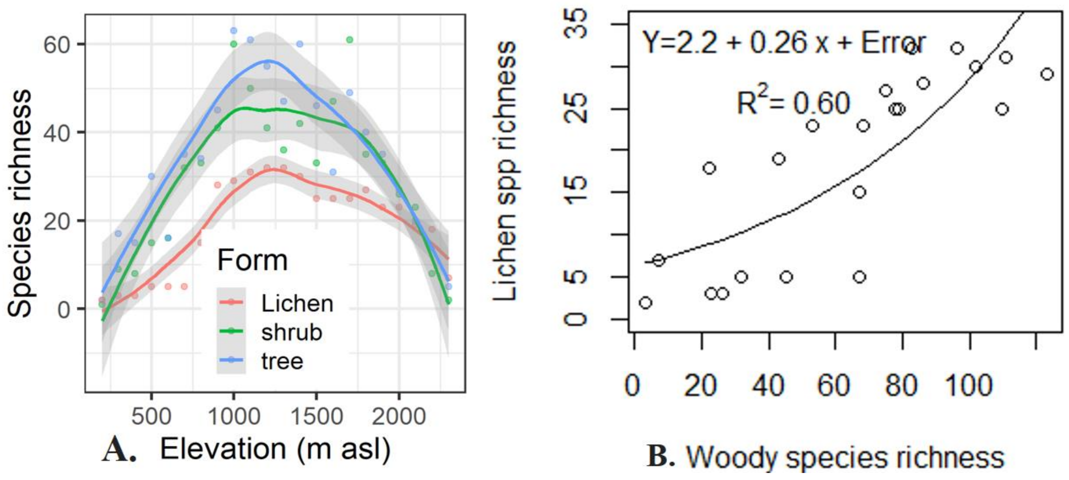


Figure 26: The regression result of, (**A**) Lichen species and its host species (trees and shrubs) against elevation (lichen- R^2= 0.83, trees- R^2 = 0.84, shrub- R^2 = 0.74 at $p < 0.05$) & (**B**) Lichen species versus host species

4.4.5 The relationship of lichen species with environmental factors

The multivariate analysis helps to demonstrate the relation between species composition and their environental factors. So, ordination method DCA and CCA applied to show relationsip of lichen species with their habitat and other environmental factors.

Table 7. Biplot score of CCA of lichen species

Axis	**Ele**	***horea***	***Shorea-Diplo***	***Shorea-Schima-Pinus***	***Quercus-Rhodo***	**Soil-Rock**	**North aspect**	**South aspect**
CCA1	0.92*	-.76*	-0.4	0.17	0.71	0.064	0.68	-0.09
CCA2	-0.32	0.48	0.81*	0.69*	-0.64	0.34	0.54	0.27

*Significance: $p < 0.05$

The CCA biplot result confirmed that elevation was a significant factor in determining the dispersal of lichen species (canonical correlation r =0.95) on first axis, but *Shoea* forest obtained the negative relation (r=-0.76) along CCA first axis. *Shorea-Schima-Pinus* forest and *Shorea-Diploknema* forest both displayed a substantial positive relationship with lichen species along the CCA2 axis (**Table 7**)

The following lichen species (*Eumitria baileyi.* Syn. *Usnea baileyi), Everniastrum cirrhatum, Cladonia coniocraea, Heterodermia incana* etc. were found in greater abundance at higher elevations. However, the species *Everniastrum nepalense, Cetraria islandica, Heterodermia obscurata, Lepraria lobificans,* and *Parmelinella simplicior* shown considerable dominancy at locations near to *Shorea robusta* forest and mixed *Shorea-Diploknema* forest. These two kinds of forests displayed a diametrically opposed relationship to elevation (**Figure 27**).

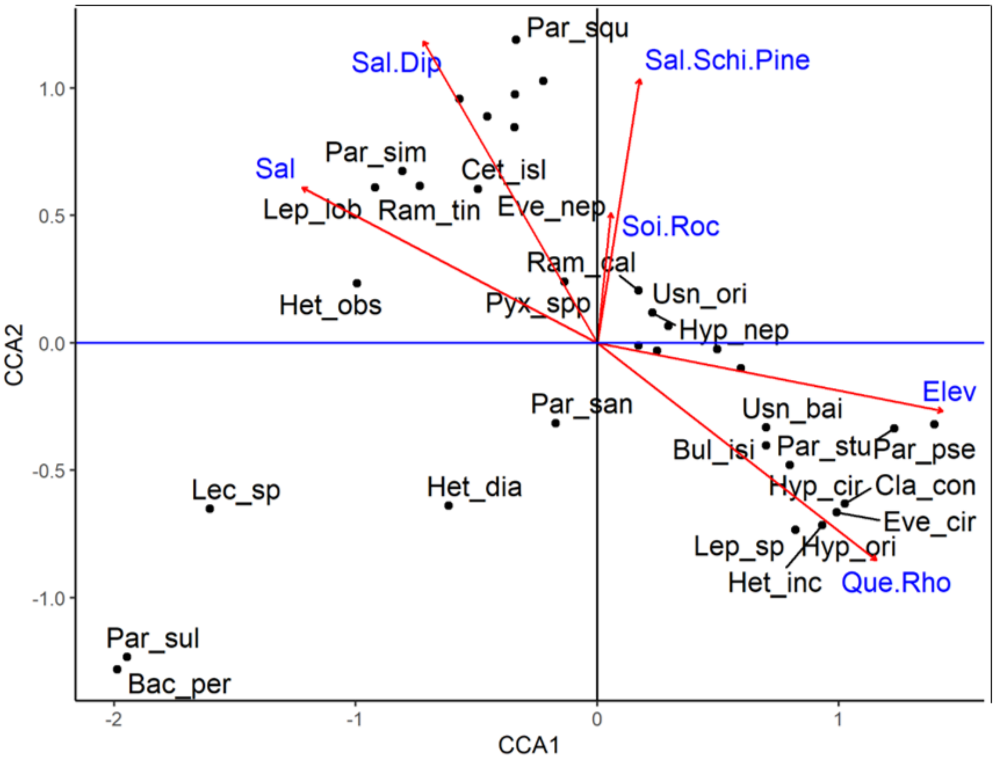


Figure 8: Lichen species-environment biplot (axis 1 and axis 2) from Canonical Correspondence Analysis ordination of vegetation of Arghakhanchi and adjoining areas.

In case of aspect of hill, North aspect showed the strong relation with lichen species distribtion than south aspect. However, they showed the less effect in lichen distribution than the forest type.

4.5 Discussion

4.5.1 Lichen diversity

In this study, 47 lichen species belonging to 10 familes and 17 genera were documented. The Physciaceae, Cladoniaceae, and Ramalinaceae families were listed in order of size, with Parmeliaceae being the largest. Baral (2015) and Baniya (2020) also supported that Parmeliaceae is the largest family in lichen species. *Parmotrema* and *Heterodermia* were the two largest lichen genera.

Foliose lichen, which covers 63.83% of total species, exhibits a remarkable diversity depending on the shape of its thallus. The existence of 35.4% crustose, 46.3% foliose, and 18.3% fruticose throughout all of Nepal supports these findings (Baniya *et al.*, 2010). The research area is the mainly hills of tropical and subtropical zone, as evidenced by the study area having very little crustose lichen (8.51%) compared to all of Nepal. Out of three ecological regions, more species were present in Sub-trop region but crustose shows the decreasing pattern from tropical to temperate regions. This outcome contrasts with lichen species present in overall Nepal, where the most lichen is found in temperate and subalpine regions (Baniya, 2020). The temperate and sub-alpine regions offer a wide array of environments for high lichen richness due to the trees and shrubs with bark that varies in roughness, moisture retention capacity, and pH (Baniya *et al*., 2010). The presence of more species in the Sub-trop region than the temperate region may be explained by the inclusion of a small portion of the temperate region (2100-2300 m) in this study area and the presence of short elevational distribution range in comparision of elevational range of entire Nepal. According to earlier researcher (Chongbang *et al.*, 2018), higher elevations have a higher lichen diversity than lower elevations in case of Nepal.

The corticolous lichen is found dominant among its lichen relatives that are found in different types of habitats. It was supported by the occurrence of more corticolous lichen species in overall Nepal (Baniya *et al*., 2010) and tropical low land forests (Lakatos *et. al*., 2006).

On the basis of forest types, the *Shorea- Schima- Pinus* forest obtained the greatest lichen diversity, whereas soil or rock had the low diversity. *Parmelinella wallichiana* and *Septotrapelia usnica* were the species that were found in all habitats. The richness of lichen species may be variable according to particular host species. According to Stikane *et al.* (2017), *Quercus* trees have the large number of lichen species. But the focus of our investigation is on different forest types rather than a specific host species. Tree species richness and their DBH (diameter at breast height) are positively linked with the makeup of the lichen community (McDonald *et al*., 2017).

But, more diversity was discovered to be positively correlated with moisture content and tree age (Jesberger & Sheard, 1973). Lichens are poikilohydric creatures which are strongly connected to moisture, solar radiation and temperature (Nash, 1990; Green *et al*., 2008; Kranner *et al*., 2008). Lichens are extremophiles and remain alive in places no other plant can due to their desiccation-tolerance (Kranner *et al.*, 2008).

The deforestation greatly affects the lichen diversity as well other epiphytic communities in tropical rain forests (Barthlott *et al*., 2001; Gradstein & Sporn, 2010; Benítez *et al*., 2015). There is a forest that is less disturbed, the host plants are old, and the average annual humidity is above 80%, which comes to the conclusion that this place is relatively rich in lichen species.

4.5.2 Lichen-Environment relationship

According to the GLM regression analysis result, total lichen as well as thalluse based lichen species displayed a statistically significant unimodal pattern against elevation. Baniya *et al.* (2010) provided support for it using same pattern of lichen species over all of Nepal. The unimodal structure of lichen species against elevation was formed due to high species turn over rather than nestedness in Himalayan arc (Nanda *et al*., 2021). Although the peak elevation value was found variable, the individual thallus form lichen species also revealed the statistically significant hump shaped elevational pattern.

The host woody species (trees and shrubs) also exposed the significant hump shaped structure with elevation. The formation of peak of species richness pattern of lichen species and its host species at more or less similar elevation indicates that the high diversity region of tree and shrubs favors for high diversity of lichen. The lichen species also showed the significant increasing linear pattern with host species richness. These two results supports the hypothesis that more host species favors for high lichen diversity.

In this, the peak elevation of the highest species richness of foliose and crustose species was found in 1600 m and 800 m respectively. These peak elevations are comparatively low in comparision to peak elevation of entire elvation of Nepal (Baniya, *et al*., 2010). This may be presence of short elevation range of study area.

According to the CCA ordination, vegetation type was discovered to be a significant influence in differentiating lichen composition in this study. The following lichen species (*Eumitria baileyi, Everniastrum cirrhatum*) were found in greater abundance in *Quercus-Rhododendron* forest at higher elevations. Chongbang *et al.* (2018) provided support for the existence of these species in temperate forest. At locations with *Shorea robusta* forest and mixed *Shorea-Diploknema* forest, consist of less dominant species of lichen species than *Quercus-Rhododendron* forest. It might be as a result of less moisture being present as a result of the temperature rising near low elevation. In tropical forests of Nepal, dominant crustose lichen species are: *Lecanora, Lecidia, Bullia, Caloplaca, Bacidia, Pertusaria, Pyxine,* and foliose species include *Dirinaria, Physcia, Parmelia, Leptogium, Collema,* and others (Baniya *et al.,* 2017). The lichen species present in sal forest of India also supports this result (Satya *et al.,* 2005).

The lichen diversity was found high in *Shorea-Schima-Pinus* forest. This was supported by presence of the crustose lichens species of *Anthracothecium, Pyrenula, Lecidea, Bacidia*, and *Pyxine*, as well as foliose species *Heterodermia, coccocarpia, Leptogium, Collema, Physia, Parmelia* in habitats made by the tree species *Schima wallichii, Castanopsis indica, Pinus roxburghii, Acer oblongum,* and *Alnus nepalensis* (Upreti & Singh, 1993; Baniya *et al.*, 2017).

According to ordination result, the north showed a marginally stronger link with lichen distribution than the south aspect of the hill. In Nepal, the north face of the hills is generally more humid than the south, and the existence of lichen species is strongly associated with moisture content. The presence of more lichen in the north was validated on the fact that decreasing lichen species in corticolous communities (Yarranton**,** 1972) and saxicolous communities (Armstrong, 1974) in response to variations in the substratum's aspect. It was also supppted by strong positive connection between host woody species and the richness and diversity of epiphytic lichen (Roper, 2018) in deciduous and conifer forest of Michigon. On south- and north-western-facing rock surfaces, however, Armstrong (1975) reported no noticeable changes in the mean growth rates of *Parmelia glabratula* sp. *fuliginos*a populations.

This study finds that moisture is the primary factor influencing lichen distribution, with hill aspect having less effect than forest type. The NCAR (net carbon assimilation) rises when a lichen thallus's water content reaches its ideal level (between 65 and 90% for terrestrial lichen) (Kershaw, 1972). The fundamental cause of the lichens' adaption to the best-moisture-content rock surface (Orwin, 1972). The other influencing factors of lichen species are natural facors: high pollution level, land slides, firing and anthropogenic factors- deforestation etc. This reseach shows the study area is comparatively less polluted and having matured host plant species. The highest elevation limit of a certain species cannot be identified on the basis of this work due to the research area's limited elevation range. This suggests that substratum wetness, rather than hill aspect, mediates the link between lichen diversity and forest type. Similar to this, lichen's great diversity reveals a roughly proportional link with host diversity.

The lichen also shows negative relationships with other species and environments. *Evernia. esorediosa* exhibits an allelopathic effect toward *Larix gmelinii* through the migration of Usnic acid, which led to inhibition of energetic processes in cells as well as slow down in tree growth and could ultimately lead to its death ((Vitalievich *et al*., 2023). However, the most notable environmental variable for lichen distribution is elevation which is supported by finding of Sevgi *et al.*, (2019).

4.6 Conclusions

The variety of lichens species, their elevational distribution pattern, and their connection to different forest types are all highlighted in this study. In total, 47 lichen species related to 17 genera and 10 families are found the Arghakhanchi district and its connecting areas. Both the lichen species and their host plant species showed the significant unimodal pattern against elevation. The high diversity of lichen and the host species they inhabit at around the same elevation suggests that vascular species diversity encourages in the existence and growth of lichen. The composition of the lichen species revealed considerable positive correlations with various forest types rather than hill aspect. Understanding the variety and usage of the lower Himalayan lichens found in Nepal can be crucial for comprehending lichen consumption and may necessitate more in-depth study in the future.

5. DISCUSSION

The major goal of this work was to determine the vascular and lichen diversity pattern and their relationship with abiotic environmental variables in Arghakhanchi and its small adjoining area (Resunga forest of Gulmi district), west Nepal.

5.1 Vascular plant diversity

The vascular plant diversity reports that there are altogether 606 species related to 123 families and 418 genera (**Table 1**). Leguminosae (Fabaceae) is the biggest family among the vascular plants (**Figure 6**) and Phanerophytes is the life-form with the highest species richness (**Table 2**). Dominance of Phanerophytes is similar to previous studies: Candido *et al.* (2019) and Severin *et al.* (2020) would be the rich life form in majority of the area. Most Phanerophytes are perennial that survive at areas having annual rainfall low to high (< 150 to > 500 mm) (Danin & Orshan, 1990). The mean value of Shannon-Wiener index (2.75), Simpson index (0.89) and evenness (0.84) of total vascular plant species indicated that the vascular plant diversity in this study area lies at the moderate category (**Table 3).** Biodiversity indices are frequently employed tools to quantify certain area through fluctuations in dispersal and abundances of species and track their management goals (Okpiliya, 2012; Giljohann *et al.*, 2017). Major findings of this research in line with most common findings done elsewhere which demonstrates that the present study area is rich, highly diverse ecological zone of tropical and subtropical flora. Variety of floral species and their life-forms significantly supported by local climate, as well as to some extent of regional influence for plant-biogeographic relationships.

This study demonstrated that there were no significant different species in Sh*orea* forest, mixed Pine and mixed conifer woodlands, however, mixed Pine woodland obtained the highest species richness (**Figure 7 A**). Similarly, the species present in both aspects of forests were not found uniform (**Figure 7 B**). This conclusion was supported by Yang *et al.* (2020) and Zhang *et al.* (2022). Due to availability of high moisture and less solar radiation, north-faced areas are typically associated with better species diversity, higher biomass, and coverage than south-faced areas (Maren *et al.,* 2015).

The result of quantitative vegetation analysis shows that *Capillipedium assimile* has the highest IVI value (138.33, 119.10 & 92.65) among all three ecological zones (tropical, Sub-tropical and temperate respectively) (**Figure 11**), which indicates that *Capillipedium assimile* is the most leading and abundant vascular plant species. The importance value index (IVI) measures the floristic variety of forest systems, which is an essential component in guessing out a species' ecological importance in a particular ecosystem (Gonçalves *et al.,* 2018). Pandey & Bajracharya (2010) also found that *C. assimile* is the dominant species in the both subtropical and temperate forests of Nepal. Other dominant species are: *Saccharum spontanuem, Oxalis corniculata, Cynodon dactylon, Imperata cylindrica* and *Reinwardtia indica* among which most of them are monocots (**Figure 8-12** & **Annex 4**). Among Therophyte life-form, *Ageratina adenophora* and *Ageratum conyzoides* have IVI values 42.02 and 40.55 in tropical region but *A. conyzoides* and *A. adenophora* obtained the highest IVI values 57.83 & 42.83 in Sub-tropical and 37.71 and 30.57 in temperate region. All ecological regions of this area shows the suitable habitats for the invasive alien species *Ageratina adenophora.* It was also supported by Poudel *et al.* (2020). According to Pathak & Misra (2016), herbaceous species are dominant species than other species in forests and grasslands. This is also applied in this area.

Shorea robusta is the most prevalent woody species. It shows the clear picture of pure Sal forest below 1000 m elevation in the south aspect and mixed *Shorea* forest below 1500 m in the both aspects of the landscape. This view was supported by Godar (2021) in study of Chure range at surrounding region of Butwal, Nepal. It may be deduced that the present study area has tropical, subtropical, and temperate type of floral vegetation with high IVI values of *Shorea robusta* (79.56) below 1000 meters, *Pinus roxburghii* (28.29) between 1000 and 2000 meters, and *Rhododendron arboreum* (92.88) at elevations over 2000 meters (**Figure 8**). This result is in line with results of the forest division done by Stainton (1972).

5.2 Vascular species- Environment relationship

The regression outcome demonstrated that the total vascular species (F**igure 13. A**) as well as individual life form species richness (**Figure 13. B**) showed statistically significant unimodal patterns with elevation. This conclusion is supported by many studies done in Nepal (Bhattarai & Vetaas, 2003; Bhattarai *et al*., 2004; Bhatta & Chaudhary, 2009;

Bhattarai *et al*., 2014; Subedi *et al*., 2015; Bhatta *et al.,* 2018; and Nepali *et al.*, 2020) as well as studies done in many mountains from outside Nepal (Grytnes and Beaman, 2006; Lee *et al.*, 2012; Namgail *et al*., 2012; Hu *et al*., 2017; Sun *et al*., 2020). Various factors have been found to contribute to the hump shaped pattern: mid-domain effect (Lee *et al.,* 2012), climate (Liang *et al.,* 2020), the combined effects of climate and competition (Wang *et al.,* 2018), edge effects (Shrestha & Vetaas, 2009) etc. Single explanatory factor can not explain the species richness patterns (Hu *et al.,* 2017). Elevational species richness patterns expose broad-scale diversity mechanisms that are influenced by temperature and water (Zhao *et al.,* 2005; McCain; 2007). Likewise, environmental heterogeneity (Stein *et al.,* 2014) and geometric constraints (Qian *et al*., 2022) also explained the large scale pattern. Among patterns, the unimodal richness pattern is believed to be a universal pattern (Hrivnák *et al.*, 2014; Rahbek 1995, 1997) and the middle elevation peak is linked with the transition zone between the flora ranges of two or more zones (Bhattarai & Vetaas, 2003). Elevation creates the topographical and climatic variation (Thorne *et al.*, 2022) and functions as the main crucial factor of ecosystem possessions and processes in the mountain regions (He *et al.*, 2016). Therefore, elevation significantly contributes to the development of unimodal patterns in the distribution of species in mountainous region. The existence of distinct eco-physiological characteristics may reflect the existence of different life form-specific elevation patterns (Cirimwami *et al.*, 2019). However, much of them agreed that vascular plants show unimodal pattern along elevation.

Due to unequal elevation range in two aspects (south and north) of hill, the species present in same elevation range was applied, which showed the insignificant relationship with elevation (**Figure 14 A**). Elevational ascents show intricate variation in abiotic environments within short spaces in Himalayan region and the pattern of species richness varies within taxonomic groupings (McCain & Grytnes, 2010). There was a 2200 m elevation range throughout the studied area, but the two aspects had a common elevation range of 1400 m. This demonstrates that when the range is shortened to 1400 m, the unimodal richness pattern that is found in long elevation ranges is transformed into a linear form. It can be concluded that unimodal species richness pattern is only appropriate for high elevation ranges and is not the best and ultimate pattern for elevation-species interaction in short elevation ranges.

By comparing the results of Pearson's correlation coefficients (**Table 5**) and PerManova correlation coefficients (**Annex 5**), it can be concluded the environmental factors showed stronger relation to species composition than species richness. The consequence of environmental factors on species alignment is relatively simpler to research than the impact of variables on species richness. Elevation has a stronger correlation to species composition than with species richness. It is quite normal that the richness is the sum of more than one species. No two species are having same ecological niche. Thus, heterogeneity of environmental gradient exists with existence of heterogeneity in species composition.

On the basis of correlation result, the elevation plus soil nitrogen were significantly negatively associated with species richness of Hemicryptophytes, Therophytes, and total vascular species richness (**Table 5**). Bhandari & Zhang (2019) claimed that elevation orders a more positive connection between plant species richness and biomass than soil nutrients in Himalayan Range. Ohdo & Takahashi's (2020) study indicated a positive link between soil nitrogen accessibility and the variety of tree and fern species, however Han *et al.* (2022) discovered a negative correlation between species richness, soil nitrogen, and soil moisture content over an elevation gradient. Thus, it can be said that the majority of plant groups' species richness exhibits a negative positive relationship with elevation, although not always with soil nutrients.

The PerMANOVA result (**Annex 5**) demonstrates that the soil nutrients and species composition have a significant association but not with elevation and climatic conditions. Elevation is a complicated mixture of more than one climatic variables, which influences on the structure and organization of communities (Stevens, 1992). In addition to temperature fluctuations and the precipitation, the qualities of soil present in varied elevation greatly influence on plant distribution and abundance (Polis, 1991). The elevation variable with interaction of other one or more explanatory variables shows statistical significant relationship with species composition (**Annex 5**). According to Mahdavi *et al.*, (2013), the ecological effects of elevation on species diversity and the distribution of living forms can noticeably explain by temperature, soil moisture, and nutrients.

It is challenging to understand the intricate relationships that exist between flora, soil, and topography and climate. The interactions between abiotic and biotic variables influence the distribution of species either cooperatively, competitively, or independently of one another (Mott, 2010; Yilmaz *et al.*, 2017; Rodríguez *et al*., 2018). The robust optimization of problems impacted by parametric errors in species distribution is made possible by ordination analysis (Rehman & Langelaar, 2015). This leads to the conclusion that the presence of many unconstrained factors and their interactions determine the existence and dissemination of species in any given region.

Ordinations in this study demonstrated that Hemicryptophytes, Phanerophytes, and Therophytes have a strong positive relationships with elevation and soil nitrogen, but Chamaephytes and Geophytes have substantial negative relationships. This finding is supported by Pavon *et al*. (2000) and Cordeiro & Neri (2018). This summarizes that N has the similar life specific response as elevation and many plants like: *Desmodium laxiflorum, Pedicularis bifida,* and exhibit high abundance at high N-containing soil. In contrast, Wang *et al.* (2007) discovered a negative association between N and P with plant variety in alpine meadows. The Chemaephytes, Hemicryptopytes and Phanerophytes show the strong negative relationship with K of soil in this case. Potassium has a significant impact on a plant's metabolism and is necessary for nutrient uptake (Sustr *et al*., 2019), availability (Sardans *et al*., 2012). Photosynthesis (Zahoor *et al*., 2017), drought tolerance, enhanced winter hardiness (Anschutz *et al*., 2014), cellular growth, wood formation and protein synthesis.

pH is statistically significantly positively associated with Chamaephytes, Hemicryptophytes, and Phanerophytes species. Gough *et al.,* (2000) and Schuster & Diekmann, (2003) also found the similar finding. It effects on plant nutrient and their cycling and soil remediation that have an impact on plant development and biomass production (Neina, 2019). So, being as master element, pH shows variable effects (either positive or negative) on plant growth and their distribution along with other variables. In this study, pH is positively correlated with the majority of plant life form composition but not with their species richness.

The CCA ordination confirmed that a number of environmental factors significantly affected the species composition of plant life forms. The influence of variables varies on the different plant life forms. The distance based matrix data and their analyses showed that the interaction of two or more factors influence more to species composition than species richness. Elevation is unquestionably a significant factor in mountainous areas. It has significant impact on the types of soil and soil formation processes (Baumler and Zech, 1994) and supplies sufficient nutrients and water to plants (Davies *et al.,* 2007)   It certainly has a significant influence in controlling species composition by producing a variety of habitats, combined with variations in water availability and temperature (Han *et al*., 2022) and variations in soil nitrogen (Wang *et al*, 2007; Korner, 2000; Shovan *et al.,* 2020). The combination of two or more ecological factors, rather than by a single factor represent the strongest predictor of biodiversity (Pausas and Austin, 2001; Dufour *et al*., 2006).

Plant communities are dynamic systems that are always changing due to local elimination and immigration (Morris *et al.*, 2014). The species composition as a response variable is clearly beneficial for studies of landscape ecology and biogeography than species richness (Aggemyr *et al.*, 2018). Therefore, species composition should be used as a reliable and instructive indicator of variety for biogeography and conservation forecasting.

5.3 Environment-Lichen interaction

The lichen study revealed that there are 47 species of lichen in 17 genera and 10 families (**Annex 12**). The Parmeliaceae is listed as the largest family (**Figure 21**). Baniya (2020) also supported that Parmeliaceae is the largest family in lichen species of Nepal. The trees and shrubs with bark that varies in roughness, moisture retention capacity, and pH favors for high lichen diversity in the temperate and sub alpine regions of Nepal (Baniya *et al*., 2010). According to earlier research (Chongbang *et al.,* 2018), higher elevations have a higher lichen diversity than lower elevations in case of Nepal. It is quite common that the lichen richness is comparatively less in the lower elevation and tropical to subtropical zones than other ecological regions in Nepal.

Foliose lichen, which covers 63.83% of total species, exhibits a remarkable diversity depending on the shape of its thallus (**Figure 22 A**). This outcome is comparable to the discovery of lichen across the entirety of Nepal (Baniya *et al*, 2010). The result of presence of more corticolous lichen species may due to presence of woody mature plants. This was supported by presence of more corticolous species present in overall Nepal (Baniya *et al*., 2010) and tropical low land forests (Lakatos *et. al.,* 2006).

According to the GLM regression result, both the lichen species and host species (trees and shrubs) displayed a statistically significant unimodal pattern against elevation. Findings by Baniya *et al.* (2010) of all of Nepal confirm this conclusion. The unimodal structure of lichen species against elevation was formed due to high species turn over (Nanda *et al.,* 2021). The formation of peak of species richness pattern of lichen species and its host species (tree and shrub) at more or less similar elevation (**Figure 27 A**) and higher value of coefficient of determination (R^2) (**Figure 27 B**) indicates that the high diversity region of tree and shrubs favors for high diversity of lichen. This conclusion accepted the proposed hypothesis.

According to the CCA ordination, vegetation type was discovered to be a significant influence in differentiating lichen community composition (**Figure 28**) in this study. The lichen species were found in greater abundance in *Quercus-Rhododendron* forest at higher elevations. It was supported by finding of Chongbang *et al.* (2018).

The result shows that mixpine (*Shorea- Schima- Pinus*) forest had the highest lichen diversity and *Parmelinella wallichiana* and *Septotrapelia usnica* are found in all habitats. This conclusion aligns with those of Baniya *et al.* (2017) in the tropical region of Nepal and Satya *et al.* (2005) in the Sal forest of India. This was also supported by presence of the crustose and foliose lichens species in habitats made by the tree species *Schima wallichii, Castanopsis indica, Pinus roxburghii, Acer oblongum,* and *Alnus nepalensis* (Upreti & Singh, 1993).

According to ordination result, the north showed a marginally stronger link with the lichen species distribution than the south aspect of the hill. It was validated by fluctuation in lichen species in both corticolous communities (Yarranton**,** 1972) and saxicolous communities (Armstrong, 1974) in response to variations in the substratum's aspect. The best-moisture-content substratum or nature of barks (McDonald *et al*., 2017) is the primary driver of the lichens' adaptation, and the rate of net carbon assimilation (NCAR) governs the growth of the lichen thallus (Kershaw, 1972). More diversity of lichen positively correlated with moisture content and tree age (Jesberger & Sheard, 1973). This suggests that substratum wetness, rather than hill aspect, facilitates the link between lichen diversity and forest type. Similar to this, lichen's great diversity reveals a roughly proportional link with host diversity

5.4. Connection of vascular-lichen species with environment

The environment, vascular plants and lichen are strongly interrelated. The suitable environment favors for existence of more species abundance and species alignment of both vascular plants and lichens. It helps to indicate the certain area is biodiversity rich. Biodiversity is hampered by both natural and man-made disturbances including landslides, fires, and deforestation. Several studies have shown that forest disruption seriously affects the diversity of epiphytic plants in different forests (Gradstein & Sporn 2010; Benítez *et al*., 2015).

Lichen is a good example of symbiotic relationship between the algae and fungi. Although lichens appear to be non-living, they exhibit several environmental indicators, including soil and air moisture levels, the variety and abundance of their host (woody) plants, type of forest and level of disturbance in the forest. Lichens, being as poikilohydric organisms, strongly link to humidity, solar radiation and temperature (Nash, 1990; Green *et al*., 2008; Kranner *et al*., 2008). As a result of their daought -tolerance, lichens are extremophiles and can remail alive in places where no higher plant can (Kranner *et al.,* 2008). Particular lichen species are usually necessary for pedogenesis, function as important tool for measuring air quality and survival of many healthy ecosystems. Due to their role as a food supply and habitat for several creatures, including deer, birds, and rodents, they are a keystone species in many ecosystems. Lichen builds up a variety of chemical nutrients inside their tissues, creating a huge image inside a tiny organism. Existence of living things therefore seems to be impossible without these three factors. The condition and interaction among these may help to prepare conservation plans for governments, INGOs, NGOs and local governments.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The conclusions of this research work are as follows:

a) There are altogether 606 species of vascular plants belonging to 123 families and 418 genera and 47 lichen species belonging to 17 genera and 10 families in Arghakhanchi district and adoining area (Resunga forest of Gulmi district).

b) According to the Raunkier's life forms, the Phanerophtes has the highest species (gamma diversity): 264 species (43.24%) and the Chamaephytes has the lowest: 37 species (6.11%) richness.

c) The value of Shannon-Wiener index (H) - 2.75, Simpson index (D) - 0.89 and Pielou evenness (E)- 0.79 indicates the vascular species have moderate diversity. Among the life forms, phanerophytes shows the leading value.

d) The regression analysis showed that all life forms and total species followed a statistically significant unimodal trend with respect to elevation.

e) Most of the life form species richness show statistically significant negative relationship with elevation and soil nitrogen.

f) In comparison to species richness, the explanatory variables showed a stronger relationship with species composition.

g) On the basis of distance based matrix analysis, soil factors show the significant role in species composition than elevation and climatic factors.

h) Phanerophytes, Hemicryptophytes, and Therophytes species structure showed a statistically significant positive link with elevation and soil nitrogen, whereas Chamaephytes and Geophytes showed a negative correlation.

i) Elevation brings changes in composition of other environmental factors show significant role in species richness as well as species composition rather than single elevation in mountainous areas.

j) Against elevation, the lichen species as well as their host species (shrub and trees) displayed a substantial unimodal pattern. This shows that the high diversity of vascular plants favour for high diversity of lichen species. i.e. Vascular plants species diversity promotes lichen existence.

6.2 Recommendations

These following recommendations are given for the conservation and sustainable management of the plant resources of Arghakhanchi and its surrounding areas based on the findings of the current research:

1. Species community composition is a standard measure for species diversity in biogeography, landscape ecology and conservation planning. Such work should be replicated elsewhere.
2. Local people should be encouraged to cultivate valuable species (*Diploknema butyracea*, *Juglans regia*, *Rhus chinensis*, *Bauhinia vahlii*, *Swertia*, Bamboo, etc.) on their farmlands in order to reduce the damage on the forest as well as increase their socio-economic condition.
3. Locals and concerned stakeholders should join conservation education through specialized training programs focusing on the sustainable collection, processing, and cultivation of important plants.
4. The local authorities should launch awareness programs to manage the IAPS *(Ageratina adenophora*, *Parthenium haustonianum* etc.

7. SUMMARY

The pattern of plant species richness at low elevations in Nepal's tropical and subtropical elevation zones has received relatively little attention. Similar to this, most of the studies on elevational species richness conducted in Nepal and elsewhere demonstrate that unimodality is the most dominant pattern and that elevation is the primary determinant of the formation of the richness pattern. Due to its lesser-known studies, the portion of tropical and subtropical region found in west Nepal may be an ideal location for research on the diversity of vascular plants present in short-elevation range and the interactions between plants and their environments, including lichen diversity.

This thesis aimed to determine the vascular plants and lichen diversity and show the plants- environment interactions in Arghakhanchi district and adjoining area. Following the examination of the primary data, the resulting explanation provides a summary of the main conclusions of this study:

Vascular plants have special vascular tissue (xylem and phloem) that help to conduct water and food and help them thrive as terrestrial organisms. Vascular plants have an important role as primary producers in the majority of terrestrial ecosystems. The result showed that Arghakhanchi and adjoining area sheltered altogether 606 species of vascular plants belonging to 123 families and 418 genera were found in sampled sites in study area. Fabaceae family and *Ficus* and *Thelypteris* genera obtained the highest number of species. Any species of endemic plant was not found in this study area. According to the Raunkiaer’s life forms, the total species richness (gamma diversity) was found the highest in Phanerophytes (43.24%) and the lowest in Chamaephytes (6.11%).

The biodiversity indices values of total vascular plants: 2.75 in Shannon index, 0.89 in Simpson and 0.79 in evenness indicate that the biodiversity is moderate type in this area. The high value of Shannon-Wiener index (2.33), Simpson index (0.85) and Pielou evenness (0.84) in Phanerophytes shows that Phanerohyte species are more doinant than other life form species.

The biodiversity is unevenly distributed throughout the earth, due to variation in latitude, elevation, topography and other factors. The elevation forms the mirror image of latitude and Nepal has the longest elevational range in the world.

This in-depth ecological research demonstrates the relations between diversity within Raunkier's plant life forms (Phanerophytes, Chamaephytes, Hemicryptopytes, Geophytes, and Therophytes) distributed in the Arghakhanchi district and adjoining areas with some environmental variables (elevation, RRI, soil pH, nitrogen, phosphorus, potassium and hill aspect). This investigation demonstrated that a unimodal pattern with respect to elevation was followed by all life forms and total vascular species. The unimodal species richness-elevation connection appears to have a global distribution (Rehbek, 1997). The hump shaped structure of similarity index and reverse unimodal structure of Bray-Curtis beta diversity value indicate that the value of alpha diversity present in elevation band made peak near the mid elevation range. This higher alpha species richness appeared due to common species present in two adjoining forest or communities like: Sal forest and mixed Sal forest (main species *Shorea robusta*, *Schima wallichii* etc.). In my view, the edge effect of adjoining communities helps to shape the unimodal species richness pattern

The explanatory variables revealed stronger connections with species composition than with species richness. The elevation and soil nitrogen showed the significant negative relationships with species richness of plant life forms: Chamaephytes, Hemicryptophytes, Phanerophytes, Geophytes and Therophytes. The permutational ANOVA (PerMANOVA) result shows that elevation is not a single factor to determine the species composition. The edaphic factors: pH, N, P and K showed the significant relationships individually with specis composition than elevation and climatic factors. Elevation only in combination with other climatic facors or edaphic factors shows the significant relationship with species composition. Species richness is number but species composition means identity of species in community. So, species composition gives both richnes and distribution. In my view, species composition is stronger parameter than specis richness. Elevation brings variation in climatic, edaphic and topographic factors. The interaction of many ecological factors including elevation help to determine the of species composition in Himalayan region. The edaphic factors individually show more effect in species composition and ultimately into species richness than elevation and climatic factors. It can be concluded that edaphic factor individually or climatic facots with collaboration with elevation play role in shaping the species richness pattern through species composition in mountainous locations.

Lichens have been used as indicators of late successional ecosystems with a high conservation priority because they are widespread, sensitive to small-scale environmental fluctuation, and some species need old substrates. The variety of lichens species, their elevational distribution pattern, and their connection to different forest types are all highlighted in this study. In total, 47 species belonging to 17 genera and 10 families are found in Arghakhanchi district and its adjoining areas. Both the lichen species and their host plant species showed the significant unimodal pattern against elevation. The high diversity of lichen and the host species they inhabit at around the same elevation suggests that vascular species diversity encourages lichen composition. The composition of the lichen species revealed considerable positive correlations with various forest types rather than hill aspect. Understanding the variety and usage of the lower Himalayan lichens found in Nepal can be crucial for comprehending lichen consumption and may necessitate more in-depth study in the future.

This work is a small part of biodiversity of tropical and Sub-tropical region of west Nepal. This work accepted the proposed hypothesis, vascular plant as well as lichen species richness follow the unimodal pattern against elevation in low hills of tropical and sub-tropical region as observed in the long elevational range of entire Nepal. High species of tree and shrubs show the high lichen diversity in undisturbed places. The high species composition gives the high species richness. The environmental factors which show strong positive relationship with species composition ultimately play key role in formation of species richness pattern. The natural calamites: landsliding, soil erosion, and anthropogenic factors: deforestation, firing and over-exploitation don’t help to form the species pattern but disturb or modify the species composition and species richness. This is the small but important primary research on the study of vascular plants and lichens conducted in the small tropical and subtropical region of west Nepal. This research result demonstrates that the discovery of plant species' distribution in low mountains may aid biogeographical research and provide information to policymakers and planners for conservation objectives.

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ANNEXES

Annex 1. Cordinates and elevation of sampled sites in study area

S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation	S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation
1	Dohote	27.7627	83.0859	242	17	Durga phat	27.923	83.2642	725
2	Dhaule takura	27.7583	83.0533	247	18	Dadhuwa	27.9358	83.0278	739
3	Tikkar	27.7786	83.0586	390	19	Samne khola	28.0385	82.9826	759
4	Dohote	27.7722	83.0731	411	20	Pirapani	27.791	83.0538	770
5	Darbar danda	27.7751	83.0521	468	21	Chhaldi	28.0651	83.1067	788
6	Rajiya	27.7888	83.0626	475	22	Rosa	27.9344	83.0338	808
7	Jhimruk	27.9242	83.052	483	23	Jadi khola	27.9544	83.1668	822
8	Tikkar,Thada	27.7803	83.0524	561	24	Rithekhola	27.9545	83.1678	846
9	Badahare, Dhanchour	27.9342	83.0165	579	25	Durghaphat	27.8974	83.2558	853
10	Rajiya	27.7918	83.08	593	26	Okhate	28.0524	82.9851	860
11	Jhimruk	27.997	82.955	610	27	Rajiya	27.8151	83.0836	872
12	Baseri, Thada	27.7986	83.0481	655	28	Panku	27.9345	83.0351	872
13	Samne khola	28.0465	82.9868	661	29	Lahare kho	27.9544	83.1668	873
14	Pirapani south	27.785	83.0524	668	30	Rosa, Dhanchour	27.8962	83.2492	874
15	Dhote, Thada	27.7988	83.078	677	31	Kothia below	27.7952	83.0534	875
16	Lamdanda	27.934	83.0271	680	32	Dhakabang	28.0506	82.0506	878

S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation	S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation
33	Bhole kho	27.9574	83.1668	885	54	Samne khola	28.0497	82.9935	1021
34	Okhate, Dhakabang	28.0506	82.985	902	55	Hile Khola	27.8238	83.0635	1047
35	lahare kh	27.9527	83.162	915	56	Panku	27.9327	83.0446	1048
36	Okhate	28.0534	82.9854	940	57	Rajiya	27.8161	83.0701	1062
37	Rosa, Dhanchour	27.936	83.0346	942	58	Bhuwand	27.9501	83.1613	1075
38	Patauti	27.8426	83.2517	953	59	Pakhapani	27.8411	83.2498	1078
39	Lamdanda	27.9309	83.0367	953	60	Rosa	27.9214	83.039	1081
40	Chihandanda	27.896	83.2437	973	61	Laddakh	28.0078	83.1343	1083
41	Panku	27.9343	83.036	973	62	Okhate upper	28.0546	82.9813	1091
42	Buwandanda	27.9518	83.1602	973	63	Lamdanda	27.9337	83.0389	1094
43	Nayagaun, Maidan	27.869	83.2398	975	64	Rosa	27.9359	83.0454	1095
44	Sitkhola	27.8986	83.0548	976	65	Bhuwan	27.9461	83.1037	1096
45	Laddakh	27.985	83.1287	981	66	Rajiya tem	27.8138	83.0618	1097
46	Kothiya	27.8052	83.0515	982	67	Dhadmai	27.896	83.2437	1098
47	Sitkhola	27.8742	83.0762	987	68	Panku	27.9331	83.0372	1104
48	Bhuwandanda	27.948	83.1654	995	69	Poudi	27.9371	83.1572	1111
49	Behore	28.0995	83.248	997	70	Bhirkuna	27.8462	83.235	1118
50	Chhahare	27.9521	83.1468	998	71	Maidan	27.8941	83.2418	1130
51	Okhaldhunga	27.8691	83.0804	1002	72	Dadhuwa	27.9322	83.0598	1146
52	Bhuwandanda	27.9512	83.1614	1002	73	Simle	27.8458	83.235	1149
53	Naya gaun	27.9003	83.2392	1003	74	Rajiya	27.8139	83.0619	1151

S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation	S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation
75	Dahakhola	27.9575	83.1632	1153	96	Supa	27.8902	83.1318	1380
76	Maidan	27.8358	83.2358	1174	97	Okhate, Dhakabang	28.063	82.9782	1402
77	Jhakreni	27.8541	83.081	1176	98	Patauti	27.8856	83.2375	1421
78	Khumchikot, Thada	27.8161	83.0601	1183	99	Todke, Dhanchour	27.9214	83.0523	1428
79	Panku	27.9318	83.0434	1190	100	Ribdi, Narpani	27.9299	81.1658	1440
80	Okhate	28.06	82.9806	1195	101	Dahakhola, Narpani	27.9253	83.1576	1445
81	Dhakabang	28.0637	83.0002	1204	102	Todke	27.9331	83.0371	1451
82	Maidan	27.8906	83.2355	1217	103	Tamghasa	29.0848	83.2483	1465
83	Bhuwan	27.935	83.1609	1220	104	Makhata	28.02	83.1353	1474
84	Makhata	28.0154	83.1375	1228	105	Maidan	27.8892	83.2292	1487
85	Thada	27.8234	83.0637	1252	106	Deurali	27.9005	83.136	1490
86	Bhuwanpata	27.8863	83.1319	1253	107	Todke	27.92	83.0588	1502
87	Behore, Resunga	28.0912	83.2466	1267	108	Salleri, Dhakabang	28.0691	82.9769	1504
88	Thada	27.9365	83.1656	1278	109	Ribdi, Narapani	27.9257	83.1632	1512
89	Deurali,Panku	27.9289	83.039	1297	110	Salleri, Dhakabang	28.0748	82.9845	1512
90	Makhata	29.0173	83.1358	1338	111	Diverna	28.021	83.1463	1542
91	Sallaghari	27.9301	83.1661	1350	112	Narapani	27.9232	83.1582	1547
92	Sallaghari	27.9265	83.1577	1351	113	Amile	28.0211	83.1548	1548
93	Diverna	27.9143	83.0836	1351	114	Maidan	27.8783	83.2317	1553
94	Goldhung, Jukena	27.903	83.0568	1358	115	Sano deva	27.9248	83.1137	1584
95	Maidan	27.8927	83.2302	1363	116	Khalte	28.0776	82.9873	1592

S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation	S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation
117	Kalikathi	27.8708	83.2271	1602	136	Sengleng	27.919	83.0772	1756
118	Jalkanda	28.0219	83.1478	1605	137	Kalikathi	27.8663	83.1804	1772
119	Arichour	27.9206	83.0633	1610	138	Jalkanda	28.025	83.1463	1808
120	Dhamile khola	28.0709	83.1074	1615	139	Mulabari	27.9062	83.1456	1810
121	Narpani	27.9085	83.1426	1624	140	Satineta	27.9152	83.1575	1822
122	Kalikathi, Maidan	27.8688	83.2218	1628	141	North Jalkanda	28.032	83.1376	1826
123	Satineta	27.9165	83.1599	1652	142	Sengleng	27.9078	83.0782	1830
124	Khana, Makhata	28.0296	83.1332	1663	143	Khana, Thana	28.0494	83.1188	1830
125	Narapani	27.9177	83.1557	1672	144	Kalikathi	27.863	83.2196	1837
126	Khalte, Dhakabang	28.0805	82.9878	1672	145	North, Malarani	27.9124	83.1563	1840
127	Jalkanda	28.0237	83.1435	1674	146	Kuna Kharka	28.0705	83.1003	1842
128	Tamghas	28.0816	83.25	1687	147	Jalkanda	28.0274	83.1464	1864
129	Khana	28.0305	83.1395	1698	148	Resunga	28.0731	83.2589	1877
130	Narapani	27.9172	83.1545	1703	149	Narapani	27.9065	83.1469	1890
131	Dhamile khola	28.0697	83.1026	1703	150	Mala north	28.0634	83.1021	1895
132	Narapani	27.9097	83.1446	1716	151	Khanchi	27.9174	83.1245	1898
133	Sengleng	27.9143	83.0669	1733	152	Narapani	27.9161	83.1219	1901
134	Kalikathi	27.8659	83.2235	1735	153	Jalkanda	28.0297	83.1416	1904
133	Sengleng	27.9143	83.0669	1733	154	Sengleng	27.9064	83.0814	1915
134	Kalikathi	27.8659	83.2235	1735	155	Jalkanda	28.0304	83.1694	1920
135	khanchi	27.9254	83.1286	1744	156	Malarani	28.0685	83.0984	1936

S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation	S.N.	Name of sampled site	Latitude (°)	Longitude (°)	Elevation
157	Sengleng	27.9017	83.0906	1938	170	Gokhunga	28.0989	83.0138	2033
158	Malarani	28.0628	83.0998	1938	171	Sengleng top	27.9074	83.0859	2048
159	Kafalneti, Gokhunga	28.1027	83.0135	1956	172	Gokhunga	28.0965	83.0139	2060
160	Kafalneti	28.1011	83.0127	1958	173	Malarani	28.0666	83.0957	2065
161	Malarani	28.0674	83.0925	1989	174	Resunga	28.0687	83.2624	2072
162	Malarani	28.0674	83.0924	1996	175	Gargare, Khanchi	27.9115	83.1185	2087
163	Gokhunga	28.1	83.0129	2001	176	Malarani	28.0648	83.0945	2124
164	Malarani	28.0615	83.0953	2004	177	Malarani	28.0645	83.0933	2138
165	Gargare, Khanchi	27.9083	83.1096	2014	178	Gargare	27.9127	83.1149	2151
166	Gargare	27.9109	83.1269	2021	179	Gargare	27.9127	83.1149	2158
167	Malarani	28.0677	83.0967	2024	180	Resunga, Tower	27.0129	83.2437	2233
168	Gargare	27.9122	83.1243	2026	181	Resunga top	28.0659	83.2644	2288
169	Sengleng	27.9079	83.0863	2028					

Annex 2: List of vascular plant species according to Raunkiers' life form category

S.N.	Scientific names	Abbreviation	Family	Habit	Taxa	Life forms
1	*Abelmoschus manihot* (L.) Medik 1787	Abe_man	Malvaceae	Shrub	Dicot	Chamaephytes
2	*Abrus precatorius* L. 1753	Abr_pre	Leguminosae	Climber	Dicot	Phanerophytes
3	*Acer oblongum* Wall. ex DC. 1824	Ace_obl	Sapindaceae	Tree	Dicot	Phanerophytes
4	*Achyranthes aspera* L. 1753	Ach_asp	Amaranthaceae	Herbs	Dicot	Chamaephytes
5	*Achyranthes bidentata* Blume 1825	Ach_bid	Amaranthaceae	Herbs	Dicot	Chamaephytes
6	*Acmella calva* (DC.) R. K. Jansen 1985	Acm_cal	Asteraceae	Herbs	Dicot	Hemicryptophytes
7	*Acmella paniculata* (Wall. ex DC.) R. K. Jansen 1985	Acm_pan	Asteraceae	Herbs	Dicot	Hemicryptophytes
8	*Adenostemma lavenia* (L.) Kuntze 1891	Ade_lav	Asteraceae	Herbs	Dicot	Therophytes
9	*Adiantum capillus-veneris* L. 1753	Adi_cap	Pteridaceae	Ferns	Fern	Hemicryptophytes
10	*Adiantum incisum* Forssk. 1775	Adi_inc	Pteridaceae	Ferns	Fern	Hemicryptophytes
11	*Adiantum philippense* L. 1753	Adi_phi	Pteridaceae	Ferns	Fern	Hemicryptophytes
12	*Adiantum philippense* L. subsp. *Philippense* L. 1753	Adi_php	Pteridaceae	Ferns	Fern	Hemicryptophytes
13	*Adiantum venustum* D. Don 1825	Adi_ven	Pteridaceae	Ferns	Fern	Hemicryptophytes
14	*Adiantum caudatum* L. 1771	Adi_inc	Pteridaceae	Ferns	Fern	Hemicryptophytes
15	*Adina cordifolia* (Roxb.) Brandis 1874	Adi_cor	Rubiaceae	Tree	Dicot	Phanerophytes
16	*Aegle marmelos* (L.) Corrêa 1800	Aeg_mar	Rutaceae	Tree	Dicot	Phanerophytes
17	*Agave cantala* (Haw.) Roxb. ex Salm-Dyck 1829	Aga_can	Asperagaceae	Shrub	Monocot	Phanerophytes
18	*Agave sisalana* Perrine 1838	Aga_sis	Asperagaceae	Shrub	Monocot	Phanerophytes
19	*Ageratina adenophora* (Spreng.) R. King & H. Rob. 1970	Age_ade	Asteraceae	Herbs	Dicot	Therophytes
20	*Ageratum conyzoides* L. 1753	Age_con	Asteraceae	Herbs	Dicot	Therophytes
21	*Ageratum houstonianum* Mill. 1768	Age_hau	Asteraceae	Herbs	Dicot	Therophytes

22	*Agrimonia pilosa* Ledeb. 1823	Agr_pil	Rosaceae	Herbs	Dicot	Hemicryptophytes
23	*Albizia chinensis* (Osbeck) Merr. 1916	Alb_chi	Leguminosae	Tree	Dicot	Phanerophytes
24	*Albizia lebbek* (L.) Benth. 1806	Alb_leb	Leguminosae	Tree	Dicot	Phanerophytes
25	*Aleuritopteris dealbata* (C. Presl) Fée 1852	Ale_don	Pteridaceae	Ferns	Fern	Hemicryptophytes
26	*Aleuritopteris leptolepis* (Fraser-Jenk.) Fraser-Jenk. 2008. Syn. *Hemionitis leptolepis* (Fraser-Jenk.) Christenh. 2018	Ale_lep	Pteridaceae	Ferns	Fern	Hemicryptophytes
27	*Aleuritopteris bicolor* (Roxb.) Fraser-Jenk. 2009 Syn. *Hemionitis bicolor* (Roxb.) Christenh. 2018	Ale_bic	Pteridaceae	Ferns	Fern	Hemicryptophytes
28	*Aleuritopteris rufa* (D. Don) Ching 1941 Syn. Hemionitis gmorgana Christenh. 2018	Ale_ruf	Pteridaceae	Ferns	Fern	Hemicryptophytes
29	*Aleuritopteris subdimorpha* (C.B. Clarke & Baker) Fraser-Jenk. 2009. Syn. *Hemionitis subdimorpha* (C.B.Clarke & Baker) Christenh. 2018	Ale_sub	Pteridaceae	Ferns	Fern	Hemicryptophytes
30	*Alnus nepalensis* D.Don 1825	Aln_nep	Betulaceae	Tree	Dicot	Phanerophytes
31	*Alstonia scholaris* (L.) R. Br. 1809	Als_sch	Apocynaceae	Tree	Dicot	Phanerophytes
32	*Alternanthera sessilis* (L.) DC. 1813	Alt_ses	Amaranthaceae	Herbs	Dicot	Hemicryptophytes
33	*Amaranthus spinosus* L. 1753	Ama_spi	Amaranthaceae	Herbs	Dicot	Therophytes
34	*Amaranthus viridis* L. 1763	Ama_vir	Amaranthaceae	Herbs	Dicot	Therophytes
35	*Ammannia baccifera* L. 1753	Amm_bac	Lythraceae	Herbs	Dicot	Therophytes
36	*Ampelocalamus patellaris* (Gamble) Stapleton 1994	Amp_pat	Poaceae	Herbs	Monocot	Hemicryptophytes
37	*Ampelocissus rugosa* (Wall.) Planch. 1884	Amp_rug	Vitaceae	Climber	Dicot	Phanerophytes
38	*Anagallis arvensis* L. 1753. Syn. *Lysimachia arvensis* (L.) U.Manns & Anderb. 2009	Ana_arv	Primulaceae	Herbs	Dicot	Hemicryptophytes
39	*Anaphalis adnata* Wall. ex DC. 1838 Syn. *Pseudognaphalium adnatum* (DC.) Y.S.Chen 2011	Ana_adn	Asteraceae	Herbs	Dicot	Therophytes

40	*Anaphalis busua* (Buch.-Ham.) DC. 1838	Ana_bus	Asteraceae	Herbs	Dicot	Therophytes
41	*Anaphalis margaritacea* (L.) Benth. & Hook.f. 1873	Ana_mar	Asteraceae	Herbs	Dicot	Therophytes
42	*Anaphalis triplinervis* (Sims) C. B. Clarke 1876	Ana_tri	Asteraceae	Herbs	Dicot	Therophytes
43	*Anisomeles indica* (L.) Kuntze 1891	Ani_ind	Lamiaceae	Herbs	Dicot	Chamaephytes
44	*Antidesma acidum* Retz. 1788	Ant_aci	Phyllanthaceae	Tree	Dicot	Phanerophytes
45	*Ardisia humilis* Vahl 1794	Ard_sol	Primulaceae	Tree	Dicot	Phanerophytes
46	*Argemone mexicana* L. 1753	Arg_mex	Asteraceae	Herbs	Dicot	Therophytes
47	*Argentina lineata* (Trevir.) Soják 2010	Arg_lin	Rosaceae	Herbs	Dicot	Hemicryptophytes
48	*Argyreia argentea* (Roxb.) Sweet 1830	Arg_arg	Convolvulaceae	Climber	Dicot	Phanerophytes
49	*Arisaema tortuosum* (Wall.) Schott 1832	Ari_tor	Araceae	Herbs	Monocot	Geophytes
50	*Aristolochia indica* L. 1753	Ari_ind	Aristolochiaceae	Climber	Dicot	Phanerophytes
51	*Artemisia dubia* Wall. ex Besser 1834	Art_dub	Asteraceae	Herbs	Dicot	Therophytes
52	*Artemisia indica* Willid 1846	Art_ind	Asteraceae	Herbs	Dicot	Chamaephytes
53	*Arthraxon lanceolatus* (Roxb.) Hochst. 1856	Art_lan	Poaceae	Herbs	Monocot	Hemicryptophytes
54	*Arundina graminifolia* (D. Don) Hochr. 1910	Aru_gra	Orchidaceae	Herbs	Monocot	Geophytes
55	*Arundinella nepalensis* Trin. 1826	Aru_nep	Poaceae	Herbs	Monocot	Geophytes
56	*Asclepias curassavica* L. 1753	Asc_cur	Apocynaceae	Herbs	Monocot	Geophytes
57	*Asparagus racemosus* Willd. 1799	Asp_rac	Asperagaceae	Herbs	Monocot	Chamaephytes
58	*Asplenium ensiforme* Wall. ex Hook. & Grev. 1828	Asp_ens	Aspleniaceae	Ferns	Fern	Hemicryptophytes
59	*Astilbe rivularis* Buch. -Ham. ex D. Don 1825	Ast_riv	Saxifragaceae	Herbs	Dicot	Hemicryptophytes
60	*Athyrium cuspidatum* (Bedd.) M.Kato 1977	Ath_cus	Aspleniaceae	Ferns	Fern	Hemicryptophytes
61	*Athyrium falcatum* Bedd. 1863	Ath_fal	Athyriaceae	Ferns	Fern	Hemicryptophytes
62	*Athyrium foliolosum* (Wall.) T. Moore ex Sm. 1859	Ath_fol	Athyriaceae	Ferns	Fern	Hemicryptophytes
63	*Athyrium schimperi* Moug. ex Fée 1852	Ath_sch	Athyriaceae	Ferns	Fern	Hemicryptophytes

64	*Azolla caroliniana* Willd.1810	Azo_car	Salviniaceae	Ferns	Fern	Hemicryptophytes
65	*Azolla pinnata* R. Br. 1810	Azo_pin	Salviniaceae	Ferns	Fern	Hemicryptophytes
66	*Bambusa balcooa* Roxb. 1832	Bam_bal	Poaceae	Herbs	Monocot	Geophytes
67	*Barleria cristata* L. 1753	Bar_cri	Acanthaceae	Shrub	Dicot	Phanerophytes
68	*Basella alba* L. 1753	Bas_alb	Basellaceae	Climber	Dicot	Phanerophytes
69	*Bauhinia purpurea* L. 1753	Bau_pur	Leguminosae	Tree	Dicot	Phanerophytes
70	*Bauhinia vahlii* Wight & Arn. 1852	Bau_vah	Leguminosae	Shrub	Dicot	Phanerophytes
71	*Bauhinia variegata* L. 1753	Bau_var	Leguminosae	Tree	Dicot	Phanerophytes
72	*Beaumontia grandiflora* Wall. 1824	Bea_gra	Apocynaceae	Shrub	Dicot	Phanerophytes
73	*Begonia picta* Sm. 1806	Beg_pic	Begoniaceae	Herbs	Dicot	Geophytes
74	*Berberis aristata* DC. 1821	Ber_ari	Berberidaceae	Shrub	Dicot	Phanerophytes
75	*Berberis asiatica* Roxb. ex DC. 1821	Ber_asi	Berberidaceae	Shrub	Dicot	Phanerophytes
76	*Bergenia ciliata* (Haw.) Sternb. 1831	Ber_cil	Saxifragaceae	Herbs	Dicot	Hemicryptophytes
77	*Betula alnoides* Buch. -Ham. ex D.Don 1825	Bet_aln	Betulaceae	Tree	Dicot	Phanerophytes
78	*Biancaea decapetala* (Roth) O.Deg. 1936	Bia_dec	Leguminosae	Shrub	Dicot	Phanerophytes
79	*Bidens biternata* (Lour.) Merr. & Sherff 1929	Bid_bit	Asteraceae	Herbs	Dicot	Therophytes
80	*Bidens pilosa* L. 1939	Bid_pil	Asteraceae	Herbs	Dicot	Therophytes
81	*Bistorta amplexicaulis* (D. Don) Greene 1904	Bis_amp	Polygonaceae	Herbs	Dicot	Hemicryptophytes
82	*Blechnum orientale* L. 1753	Ble_ori	Blechnaceae	Ferns	Fern	Hemicryptophytes
83	*Blumea fistulosa* (Roxb.) Kurz 1877	Blu_fis	Asteraceae	Herbs	Dicot	Therophytes
84	*Blumeopsis flava* (DC.) Gagnep. 1920	Blu_fla	Asteraceae	Herbs	Dicot	Therophytes
85	*Boehmeria platyphylla* D.Don 1825	Boe_pla	Rubiaceae	Shrub	Dicot	Phanerophytes
86	*Boenninghausenia albiflora* (Hook.) Rchb. ex Meisn. 1837	Boe_alb	Urticaceae	Shrub	Dicot	Phanerophytes
87	*Boerhavia diffusa* L. 1753	Boe_dif	Nyctaginaceae	Herbs	Dicot	Hemicryptophytes
88	*Bolbitis heteroclita* (C. Presl) Ching 1934	Bol_het	Dryopteridaceae	Ferns	Fern	Hemicryptophytes

89	*Bombax ceiba* L. 1753	Bom_cei	Malvaceae	Tree	Dicot	Phanerophytes
90	*Borassus flabellifer* L. 1753	Bor_fla	Arecaceae	Tree	Monocot	Phanerophytes
91	*Bothriochloa bladhii* (Retz.) S.T.Blake 1969	Bot_bla	Poaceae	Herbs	Monocot	Geophytes
92	*Brachiaria mutica* (Forssk.) T.Q.Nguyen 1966. Syn. *Urochloa mutica* (Forssk.) T.Q.Nguyen 1966	Bra_mut	Poaceae	Herbs	Monocot	Geophytes
93	*Brachiaria villosa* (Lam.) T.Q.Nguyen 1966 Syn. *Urochloa villosa* (Lam.) T.Q.Nguyen 1966	Bra_vil	Poaceae	Herbs	Monocot	Geophytes
94	*Brassaiopsis hainla* (Buch. -Ham.) Seem. 1864	Bra_hai	Araliaceae	Shrub	Dicot	Phanerophytes
95	*Bridelia retusa* (L.) A. Juss. 1824	Bri_ret	Phyllanthaceae	Tree	Dicot	Phanerophytes
96	*Buchanania cochinchinensis* (Lour.) Almeida 1996	Buc_lat	Anacardiaceae	Tree	Dicot	Phanerophytes
97	*Buddleja asiatica* Lour. 1790	Bud_asi	Lamiaceae	Shrub	Dicot	Phanerophytes
98	*Butea buteiformis* (Voigt) Grierson 1979	Mei_but	Leguminosae	Shrub	Dicot	Phanerophytes
99	*Caesulia axillaris* Roxb. 1798	Cae_axi	Asteraceae	Herbs	Dicot	Therophytes
100	*Callicarpa arborea* Roxb. 1820	Cal_arb	Lamiaceae	Tree	Dicot	Phanerophytes
101	*Callicarpa macrophylla* Vahl 1794	Cal_mac	Apocynaceae	Shrub	Dicot	Phanerophytes
102	*Calopogonium mucunoides* Desv. 1826	Cal_muc	Leguminosae	Climber	Dicot	Phanerophytes
103	*Calotropis gigantea* (L.) W. T. Aiton 1811	Cal_gig	Lamiaceae	Shrub	Dicot	Phanerophytes
104	*Calotropis procera* (Aiton) Aiton fil. 1811	Cal_pro	Lamiaceae	Shrub	Dicot	Phanerophytes
105	*Campanula pallida* Wall. 1820	Cam_pal	Campanulaceae	Herbs	Dicot	Geophytes
106	*Canscora alata* (Roth) Wall. 1831	Can_dec	Gentianaceae	Herbs	Dicot	Therophytes
107	*Canscora diffusa* (Vahl) R. Br. ex Roem. & Schult. 1818	Can_dif	Gentianaceae	Herbs	Dicot	Therophytes
108	*Capillipedium assimile* (Steud.) A.Camus 1922	Cap_ass	Poaceae	Herbs	Monocot	Geophytes
109	*Capparis zeylanica* L. 1762	Cap_zey	Capparaceae	Shrub	Dicot	Phanerophytes
110	*Carex baccans* Nees 1834	Car_bac	Cyperaceae	Herbs	Monocot	Geophytes
111	*Carex cruciata* Wahlenb. 1803	Car_cru	Cyperaceae	Herbs	Monocot	Geophytes

112	*Carex filicina* Nees 1834	Car_fil	Cyperaceae	Herbs	Monocot	Geophytes
113	*Careya arborea* Roxb. 1819	Car_arb	Lecythidaceae	Tree	Dicot	Phanerophytes
114	*Cassia fistula* L. 1753	Cas_fis	Leguminosae	Tree	Dicot	Phanerophytes
115	*Castanopsis indica* (Roxb. ex Lindl.) A. DC. 1863	Cas_ind	Fagaceae	Tree	Dicot	Phanerophytes
116	*Castanopsis tribuloides* (Sm.) A. DC. 1863	Cas_tri	Fagaceae	Tree	Dicot	Phanerophytes
117	*Catunaregam spinosa* (Thunb.) Tirveng. 1978	Cat_spi	Rubiaceae	Shrub	Dicot	Phanerophytes
118	*Causonis trifolia* (L.) Mabb. & J. Wen 2017	Cau_tri	Vitaceae	Climber	Dicot	Phanerophytes
119	*Cedrus deodara* (Roxb. ex D.Don) G.Don 1830	Ced_deo	Pinaceae	Tree	Gymnosperm	Phanerophytes
120	*Celastrus paniculatus* Willd. 1798	Cel_pan	Celastraceae	Climber	Dicot	Phanerophytes
121	*Cenchrus americanus* (L.) Morrone 2010	Cen_ame	Poaceae	Herbs	Monocot	Hemicryptophytes
122	*Centella asiatica* (L.) Urb. 1879	Cen_asi	Apiaceae	Herbs	Dicot	Hemicryptophytes
123	*Ceropegia johnsonii* N. E. Br.1903	Cer_mey	Asclepiadaceae	Climber	Dicot	Phanerophytes
124	*Cheilanthes albomarginata* C.B. Clarke 1880. Syn. *Hemionitis albomarginata* (C.B.Clarke) Christenh. 2018	Che_alb	Pteridaceae	Ferns	Fern	Hemicryptophytes
125	*Chenopodium album* L. 1753	Che_alb	Amaranthaceae	Herbs	Dicot	Therophytes
126	*Chlorophytum nepalense* (Lindl.) Baker 1876	Chl_nep	Asparagaceae	Herbs	Monocot	Geophytes
127	*Chromolaena odorata* (L.) R. King & H. Rob. 1970	Chr_odo	Asteraceae	Herbs	Dicot	Hemicryptophytes
128	*Chrysopogon aciculatus* (Retz.) Trin. 1820	Chr_aci	Poaceae	Herbs	Monocot	Hemicryptophytes
129	*Chrysopogon gryllus* (L.) Trin. 1820	Chr_gry	Poaceae	Herbs	Monocot	Hemicryptophytes
130	*Cinnamomum glanduliferum* (Wall.) Nees 1831	Cin_gla	Lauraceae	Tree	Dicot	Phanerophytes
131	*Cinnamomum tamala* (Buch. -Ham.) T. Nees & Eberm. 1831	Cin_tam	Lauraceae	Tree	Dicot	Phanerophytes
132	*Cirsium wallichii* DC. 1837	Cir_wal	Asteraceae	Herbs	Dicot	Therophytes
133	*Cissampelos pareira* L. 1753	Cis_par	Vitaceae	Climber	Dicot	Phanerophytes
134	*Cissus discolor* Blum 1825	Cis_jav	Vitaceae	Climber	Dicot	Phanerophytes

135	*Cissus quadrangularis* L. 1767	Cis_qua	Vitaceae	Climber	Dicot	Phanerophytes
136	*Clematis acuminata* DC. 1817	Cle_acu	Ranunculaceae	Climber	Dicot	Phanerophytes
137	*Clematis buchananiana* DC. 1817	Cle_buc	Ranunculaceae	Climber	Dicot	Phanerophytes
138	*Clerodendrum chinense* (Osbeck) Mabb. 1989	Cle_phi	Lamiaceae	Shrub	Dicot	Phanerophytes
139	*Clerodendrum infortunatum* L. 1753	Cle_inf	Lamiaceae	Shrub	Dicot	Phanerophytes
140	*Clinopodium umbrosum* (M. Bieb.) K.Koch 1849	Cli_umb	Lamiaceae	Herbs	Dicot	Chamaephytes
141	*Clitoria ternatea* L. 1753	Cli_ter	Leguminosae	Climber	Dicot	Phanerophytes
142	*Coccinia grandis* (L.) Voigt 1845	Coc_gra	Cucurbitaceae	Climber	Dicot	Phanerophytes
143	*Cocculus laurifolius* DC. 1817	Coc_lau	Menispermaceae	Tree	Dicot	Phanerophytes
144	*Coelogyne demissa* (D. Don) M.W.Chase & Schuit. 2021	Coe_dem	Poaceae	Herbs	Monocot	Hemicryptophytes
145	*Coix lachryma-Jobi* L. 1753	Coi_lac	Poaceae	Herbs	Monocot	Hemicryptophytes
146	*Colebrookea oppositifolia* Sm. 1806	Col_opp	Lamiaceae	Shrub	Dicot	Phanerophytes
147	*Colocasia esculenta* (L.) Schott 1832	Col_esc	Araceae	Herbs	Monocot	Geophytes
148	*Colocasia fallax* Schott 1859	Col_fal	Araceae	Herbs	Monocot	Geophytes
149	*Colquhounia coccinea* Wall. 1822	Col_coc	Lamiaceae	Shrub	Dicot	Phanerophytes
150	*Combretum roxburghii* Spreng. 1825	Com_rox	Combretaceae	Climber	Dicot	Phanerophytes
151	*Commelina paludosa* Blume 1827	Com_pal	Commelinaceae	Herbs	Monocot	Hemicryptophytes
152	*Coniogramme fraxinea* (D.Don) Fée ex Diels 1899	Con_fra	Pteridaceae	Ferns	Fern	Hemicryptophytes
153	*Conyza stricta* (Willd.) Raizada 1959	Con_str	Asteraceae	Herbs	Dicot	Therophytes
154	*Cordia dichotoma* G. Forst. 1786	Cor_dic	Boraginaceae	Tree	Dicot	Phanerophytes
155	*Coriaria napalensis* Wall. 1832	Cor_nep	Coriaceae	Shrub	Dicot	Phanerophytes
156	*Cotoneaster microphyllus* Wall. ex Lindl. 1827	Cot_mic	Rosaceae	Shrub	Dicot	Phanerophytes
157	*Crassocephalum crepidioides* (Benth.) S. Moore 1912	Cra_cre	Asteraceae	Herbs	Dicot	Therophytes
158	*Crinum amoenum* Ker Gawl. ex Roxb. 1817	Cri_amo	Amaryllidaceae	Herbs	Monocot	Geophytes
159	*Crotalaria alata* Buch. -Ham. ex D.Don 1825	Cro_ala	Leguminosae	Herbs	Dicot	Therophytes

160	*Crotalaria albida* B.Heyne ex Roth 1821	Cro_alb	Leguminosae	Herbs	Dicot	Therophytes
161	*Crotalaria calycina* Schrank 1817	Cro_cal	Leguminosae	Herbs	Dicot	Therophytes
162	*Crotalaria sessiliflora* L. 1763	Cro_ses	Leguminosae	Herbs	Dicot	Therophytes
163	*Cryptolepis buchananii* R.Br. ex Roem. & Schult. 1819	Cry_buc	Apocynaceae	Climber	Dicot	Phanerophytes
164	*Curculigo orchioides* Gaertn. 1788	Cur_orc	Hypoxidaceae	Herbs	Monocot	Geophytes
165	*Curcuma caesia* Roxb. 1810	Cur_cae	Zingiberaceae	Herbs	Monocot	Geophytes
166	*Cuscuta reflexa* Roxb. 1798	Cus_ref	Convolvulaceae	Climber	Dicot	Phanerophytes
167	*Cyanotis cristata* (L.) D.Don 1825	Cya_cri	Commelinaceae	Herbs	Monocot	Hemicryptophytes
168	*Cyanotis vaga* (Lour.) Schult. & Schult.f. 1830	Cya_vag	Commelinaceae	Herbs	Monocot	Hemicryptophytes
169	*Cyanthillium cinereum* (L.) H. Rob. 1990	Cya_cin	Asteraceae	Herbs	Dicot	Therophytes
170	*Cyathocline purpurea* (Buch. -Ham. ex D. Don) Kuntze 1891	Cya_pur	Asteraceae	Herbs	Dicot	Therophytes
171	*Cymbidium iridioides* D.Don 1825	Cym_iri	Orchidaceae	Herbs	Monocot	Phanerophytes
172	*Cymbopogon iwarancusa* (Jones ex Roxb.) Schult 1824.	Cym_jwa	Poaceae	Herbs	Monocot	Hemicryptophytes
173	*Cymbopogon pendulus* (Nees ex Steud.) W.Watson 1882	Cym_pen	Poaceae	Herbs	Monocot	Hemicryptophytes
174	*Cymbopogon pospischilii* (K. Schum.) C.E.Hubb 1949	Cym_str	Poaceae	Herbs	Monocot	Hemicryptophytes
175	*Cynodon dactylon* (L.) Pers. 1805	Cyn_dac	Poaceae	Herbs	Monocot	Hemicryptophytes
176	*Cynoglossum zeylanicum* (Sw. ex Lehm.) Thunb. ex Brand 1915	Cyn_zey	Boraginaceae	Herbs	Dicot	Therophytes
177	*Cyperus compressus* L. 1753	Cyp_com	Cyperaceae	Herbs	Monocot	Therophytes
178	*Cyperus cyperinus* (Retz.) Valck.Sur. 1898	Cyp_cyp	Cyperaceae	Herbs	Monocot	Geophytes
179	*Cyperus difformis* L. 1756	Cyp_dif	Cyperaceae	Herbs	Monocot	Therophytes
180	*Cyperus distans* L.f. 1782	Cyp_dis	Cyperaceae	Herbs	Monocot	Geophytes

181	*Cyperus hortensis* (Salzm. ex Steud.) Dorr 2014	Cyp_hor	Cyperaceae	Herbs	Monocot	Hemicryptophytes
182	*Cyperus imbricatus* Retz. 1788	Cyp_imb	Cyperaceae	Herbs	Monocot	Geophytes
183	*Cyperus rotundus* L. 1753	Cyp_rot	Cyperaceae	Herbs	Monocot	Geophytes
184	*Cyperus sanguinolentus* Vahl 1805	Cyp_san	Cyperaceae	Herbs	Monocot	Hemicryptophytes
185	*Dalbergia latifolia* Roxb. 1799	Dal_lat	Leguminosae	Tree	Dicot	Phanerophytes
186	*Dalbergia sissoo* Roxb. ex DC. 1825	Dal_sis	Leguminosae	Tree	Dicot	Phanerophytes
187	*Daphne papyracea* Wall. ex Steud. 1840	Dap_pap	Thymelaeaceae	Shrub	Dicot	Phanerophytes
188	*Debregeasia longifolia* (Burm. fil.) Wedd. 1869	Deb_lon	Urticaceae	shrub	Dicot	Phanerophytes
189	*Debregeasia saeneb* (Forssk.) Hepper & J.R.I.Wood 1983	Deb_sal	Urticaceae	Tree	Dicot	Phanerophytes
190	*Dendrobium longicornu* Lindl. 1830	Den_lon	Orchidaceae	Herbs	Monocot	Phanerophytes
191	*Dendrocalamus hamiltonii* Nees & Arn. ex Munro 1868	Den_ham	Poaceae	Herbs	Monocot	Geophytes
192	*Dendrophthoe falcata* (L. fil.) Blume 1830	Den_fal	Loranthaceae	Shrub	Dicot	Phanerophytes
193	*Dicliptera bupleuroides* Nees 1832	Dic_bup	Acanthaceae	Herbs	Dicot	Therophytes
194	*Dicranopteris lanigera* (D. Don) Fraser-Jenk. 2008	Dic_lan	Gleicheniaceae	Ferns	Fern	Hemicryptophytes
195	*Digitaria ciliaris* (Retz.) Koeler 1802	Dig_cil	Poaceae	Herbs	Monocot	Hemicryptophytes
196	*Digitaria setigera* Roth 1817	Dig_set	Poaceae	Herbs	Monocot	Hemicryptophytes
197	*Dioscorea bulbifera* L. 1753	Dio_bul	Dioscoreaceae	Climber	Monocot	Geophytes
198	*Dioscorea deltoidea* Wall. ex Griseb. 1842	Dio_del	Dioscoreaceae	Climber	Monocot	Geophytes
199	*Dioscorea pentaphylla* L. 1753	Dio_pen	Dioscoreaceae	Climber	Monocot	Geophytes
200	*Diospyros lanceifolia* Roxb. 1832	Dio_lan	Ebenaceae	Tree	Dicot	Phanerophytes
201	*Diplazium laxifrons* Rosenst. 1915	Dip_lax	Athyriaceae	Ferns	Fern	Hemicryptophytes
202	*Diplazium pectinatum* C.Chr. ex Urb. 1925	Dip_pec	Athyriaceae	Ferns	Fern	Hemicryptophytes
203	*Diploknema butyracea* (Roxb.) H.J.Lam 1925	Dip_but	Sapotaceae	Tree	Dicot	Phanerophytes
204	*Dipsacus inermis* Wall. 1820	Dip_ine	Dipsacaceae	Herbs	Dicot	Chamaephytes

205	*Drepanostachyum falcatum* (Nees) Keng f. 1983	Dre_fal	Poaceae	Herbs	Monocot	Geophytes
206	*Drepanostachyum intermedium* (Munro) Keng f. 1983	Dre_int	Poaceae	Herbs	Monocot	Geophytes
207	*Drymaria diandra* Blume 1825	Dry_dia	Caryophyllaceae	Herbs	Dicot	Hemicryptophytes
208	*Drynaria propinqua* (Wall. ex Mett.) J. Sm. ex Bedd. 1866	Dry_pro	Polypodiaceae	Ferns	Fern	Hemicryptophytes
209	*Dryopteris caroli-hopei* Fraser-Jenk. 1989	Dry_car	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
210	*Dryopteris chrysocoma* (Christ) C. Chr. 1905	Dry_chr	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
211	*Dryopteris cochleata* (D. Don) C. Chr. 1905	Dry_coc	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
212	*Dryopteris peranema* Li Bing Zhang 2012.	Dry_per	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
213	*Dryopteris sparsa* (D. Don) Kuntze 1891	Dry_spa	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
214	*Dryopteris wallichiana* (Spreng.) Hyl. 1953	Dry_wal	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
215	*Duabanga grandiflora* (Roxb. ex DC.) Walp. 1843	Dua_gra	Lythraceae	Tree	Dicot	Phanerophytes
216	*Duhaldea cappa* (Buch. -Ham. ex D. Don) Pruski & Anderb. 2003	Duh_cap	Asteraceae	Herbs	Dicot	Chamaephytes
217	*Duhaldea nervosa* (Wall. ex DC.) Anderb. 1991	Duh_ner	Asteraceae	Herbs	Dicot	Chamaephytes
218	*Dumasia villosa* DC 1826	Dum_vil	Leguminosae	Climber	Dicot	Phanerophytes
219	*Duranta erecta* L. 1753	Dur_rep	Verbenaceae	Shrub	Dicot	Phanerophytes
220	*Echinochloa colonum* (L.) Link 1833	Ech_col	Poaceae	Herbs	Monocot	Hemicryptophytes
221	*Echinochloa crus-galli* (L.) P.Beauv. 1812	Ech_cru	Poaceae	Herbs	Monocot	Hemicryptophytes
222	*Eclipta prostrata* (L.) L. 1771	Ecl_pro	Asteraceae	Herbs	Dicot	Therophytes
223	*Elaeagnus parvifolia* Wall. ex Royle 1836	Ela_par	Elaegnaceae	Shrub	Dicot	Phanerophytes
224	*Elephantopus scaber* L. 1753	Ele_sca	Asteraceae	Herbs	Dicot	Chamaephytes
225	*Eleusine indica* (L.) Gaertn. 1788	Ele_ind	Poaceae	Herbs	Monocot	Hemicryptophytes
226	*Elsholtzia ciliata* (Thunb.) Hyl. 1941	Els_cil	Lamiaceae	Herbs	Dicot	Therophytes
227	*Elsholtzia fruticosa* (D.Don) Rehder 1916	Els_fru	Lamiaceae	Shrub	Dicot	Phanerophytes
228	*Elsholtzia strobilifera* (Benth.) Benth. 1833	Els_str	Lamiaceae	Herbs	Dicot	Therophytes

229	*Emilia sonchifolia* (L.) DC. 1934	Emi_son	Asteraceae	Herbs	Dicot	Therophytes
230	*Engelhardia spicata* Lechen ex Blume 1826	Eng_spi	Juglandaceae	Tree	Dicot	Phanerophytes
231	*Equisetum arvense* L. 1753	Equ_arv	Equisetaceae	Ferns	Fern	Hemicryptophytes
232	*Equisetum ramosissimum* Desf. 1799	Equ_ram	Equisetaceae	Ferns	Fern	Hemicryptophytes
233	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult. 1817	Era_ten	Poaceae	Herbs	Monocot	Hemicryptophytes
234	*Eragrostis unioloides* (Retz.) Nees ex Steud. 1854	Era_ten	Poaceae	Herbs	Monocot	Hemicryptophytes
235	*Eranthemum pulchellum* Andr. 1800	Era_pul	Acanthaceae	Shrub	Dicot	Phanerophytes
236	*Erigeron canadensis* L.1753	Eri_can	Asteraceae	Herbs	Dicot	Therophytes
237	*Eriobotrya dubia* (Lindl.) Decne 1874	Eri_dub	Rosaceae	Tree	Dicot	Phanerophytes
238	*Eriocapitella rivularis* (Buch. -Ham. ex DC.) Christenh. & Byng 2018	Eri_riv	Ranunculaceae	Herbs	Dicot	Hemicryptophytes
239	*Eriocapitella vitifolia* (Buch. -Ham. ex DC.) Nakai 1941	Eri_vit	Ranunculaceae	Herbs	Dicot	Hemicryptophytes
240	*Erioscirpus comosus* (Wall.) Palla 1896	Eri_com	Poaceae	Herbs	Monocot	Hemicryptophytes
241	*Erythrina arborescens* Roxb. 1811	Ery_arb	Leguminosae	Tree	Dicot	Phanerophytes
242	*Erythrina stricta* Roxb. 1832	Ery_str	Leguminosae	Tree	Dicot	Phanerophytes
243	*Eschenbachia japonica* (Thunb.) J. Kost. 1952	Eri_jap	Asteraceae	Herbs	Dicot	Therophytes
244	*Eucalyptus camaldulensis* Dehnh. 1832	Euc_cam	Myrtaceae	Tree	Dicot	Phanerophytes
245	*Eulaliopsis binata* (Retz.) C.E. Hubb. 1935	Eul_bin	Poaceae	Herbs	Monocot	Hemicryptophytes
246	*Euphorbia heterophylla* L. 1753	Eup_het	Euphorbiaceae	Herbs	Dicot	Therophytes
247	*Euphorbia hirta* L. 1753	Eup_hir	Euphorbiaceae	Herbs	Dicot	Therophytes
248	*Euphorbia royleana* Boiss. 1862	Eup_roy	Euphorbiaceae	Shrub	Dicot	Phanerophytes
249	*Eurya acuminata* DC. 1822	Eur_acu	Pentaphyllaceae	Tree	Dicot	Phanerophytes
250	*Evolvulus alsinoides* (L.) L. 1762	Evo_als	Convolvulaceae	Herbs	Dicot	Hemicryptophytes
251	*Evolvulus nummularius* (L.) L. 1762	Evo_num	Convolvulaceae	Herbs	Dicot	Hemicryptophytes
252	*Fagopyrum cymosum* (Trevir.) Meisn. 1832	Fag_cym	Polygonaceae	Herbs	Dicot	Therophytes

253	*Falconeria insignis* Royle 1939	Fal_ins	Euphorbiaceae	Tree	Dicot	Phanerophytes
254	*Ficus auriculata* Lour. 1790	Fic_aur	Moraceae	Tree	Dicot	Phanerophytes
255	*Ficus benghalensis* L. 1753	Fic_ben	Moraceae	Tree	Dicot	Phanerophytes
256	*Ficus benjamina* L. 1767	Fic_ben	Moraceae	Tree	Dicot	Phanerophytes
257	*Ficus geniculata* Kurz 1877	Fic_gen	Moraceae	Tree	Dicot	Phanerophytes
258	*Ficus hispida* L. f. 1782	Fic_his	Moraceae	Tree	Dicot	Phanerophytes
259	*Ficus neriifolia* Sm. 1810	Fic_ner	Moraceae	Tree	Dicot	Phanerophytes
260	*Ficus religiosa* L. 1753	Fic_rel	Moraceae	Tree	Dicot	Phanerophytes
261	*Ficus sarmentosa* Buch. -Ham. ex J. E. Sm. 1810	Fic_sar	Moraceae	Shrub	Dicot	Phanerophytes
262	*Ficus semicordata* Buch. -Ham. ex J. E. Sm. 1810	Fic_sem	Moraceae	Tree	Dicot	Phanerophytes
263	*Fimbristylis bisumbellata* (Forssk.) Bubani 1850	Fim_bis	Cyperaceae	Herbs	Monocot	Therophytes
264	*Fimbristylis dichotoma* (L.) Vahl 1805	Fim_dic	Cyperaceae	Herbs	Monocot	Therophytes
265	*Flacourtia jangomas* (Lour.) Raeusch. 1797	Fla_jan	Salicaceae	Tree	Dicot	Phanerophytes
266	*Flemingia chappar* Buch. -Ham. ex Benth. 1852	Fle_cha	Leguminosae	Shrub	Dicot	Phanerophytes
267	*Flemingia strobilifera* (L.) W.T.Aiton 1812	Fle_str	Leguminosae	Shrub	Dicot	Phanerophytes
268	*Fragaria nubicola* Lindl. 1916	Fra_nub	Rosaceae	Herbs	Dicot	Hemicryptophytes
269	*Fraxinus floribunda* Wall. 1820	Fra_flo	Oleaceae	Tree	Dicot	Phanerophytes
270	*Galinsoga parviflora* Cav. 1795	Gal_par	Asteraceae	Herbs	Dicot	Therophytes
271	*Galium elegans* Wall. 1820	Gal_ele	Rubiaceae	Herbs	Dicot	Hemicryptophytes
272	*Garuga pinnata* Roxb. 1811	Gar_pin	Burseraceae	Tree	Dicot	Phanerophytes
273	*Gastrochilus calceolaris* (Buch.-Ham. ex Sm.) D.Don 1825	Gas_cal	Orchidaceae	Herbs	Monocot	Phanerophytes
274	*Gaultheria fragrantissima* Wall. 1820	Gau_fra	Ericaceae	Shrub	Dicot	Phanerophytes
275	*Gaultheria nummularioides* D. Don 1825	Gau_num	Ericaceae	Shrub	Dicot	Phanerophytes
276	*Gentiana pedicellata* (D. Don) Griseb. 1838	Gen_ped	Gentianaceae	Herbs	Dicot	Therophytes
277	*Geranium nepalense* Sweet 1820	Ger_nep	Geraniaceae	Herbs	Dicot	Geophytes

278	*Girardinia diversifolia* (Link) Friis 1981	Gir_div	Urticaceae	Herbs	Dicot	Chamaephytes
279	*Globba clerkei* Baker 1820	Glo_cle	Zingiberaceae	Herbs	Monocot	Geophytes
280	*Globba racemosa* Sm. 1806	Glo_rac	Zingiberaceae	Herbs	Monocot	Geophytes
281	*Glochidion heyneanum* (Wight & Arn.) Wight 1852	Glo_vel	Phyllanthaceae	Tree	Dicot	Phanerophytes
282	*Gnaphalium polycaulon* Pers. 1807	Gna_pol	Asteraceae	Herbs	Dicot	Therophytes
283	*Goniophlebium argutum* (Wall. ex Hook.) J. Sm. 1840	Gon_arg	Polypodiaceae	Ferns	Fern	Hemicryptophytes
284	*Gonostegia hirta* (Blume) Miq. 1868	Gon_hir	Urticaceae	Herbs	Dicot	Hemicryptophytes
285	*Grewia optiva* J. R. Drumm. ex Burret 1926	Gre_opt	Malvaceae	Tree	Dicot	Phanerophytes
286	*Grewia sapida* Roxb. 1824	Gre_sap	Malvaceae	Tree	Dicot	Phanerophytes
287	*Grewia sclerophylla* Roxb. 1831	Gre_scl	Malvaceae	Shrub	Dicot	Phanerophytes
288	*Grona heterocarpos* (L.) H.Ohashi & K.Ohashi 2018	Gro_het	Leguminosae	Shrub	Dicot	Phanerophytes
289	*Grona triflora* (L.) H.Ohashi & K.Ohashi 2018	Gro_tri	Leguminosae	Herbs	Dicot	Hemicryptophytes
290	*Habenaria dentata* (Sw.) Schltr. 1919	Hab_den	Orchidaceae	Herbs	Monocot	Geophytes
291	*Hedera nepalensis* K.Koch 1853	Hed_nep	Araliaceae	Climber	Dicot	Phanerophytes
292	*Hedychium ellipticum* Buch. -Ham. ex Sm. 1811	Hed_ell	Zingiberaceae	Herbs	Monocot	Geophytes
293	*Hedychium gardnerianum* Sheppard ex Ker Gawl. 1824	Hed_gar	Zingiberaceae	Herbs	Monocot	Geophytes
294	*Hellenia speciosa* (J.Koenig) S.R.Dutta 2013	Che_spe	Costaceae	Herbs	Monocot	Geophytes
295	*Heynea trijuga* Roxb. 1815	Hey_tri	Meliaceae	Tree	Dicot	Phanerophytes
296	*Himalayacalamus fimbriatus* Stapleton 1994	Him_fim	Poaceae	Herbs	Monocot	Geophytes
297	*Holmskioldia sanguinea* Retz. 1791	Hol_san	Lamiaceae	Shrub	Dicot	Phanerophytes
298	*Homalium napaulense* (DC.) Benth. 1859	Hom_nep	Salicaceae	Tree	Dicot	Phanerophytes
299	*Huperzia pulcherrima* (Wall. ex Hook. & Grev.) Pic.Serm. 1970	Hup_pul	Lycopodiaceae	Ferns	Fern	Hemicryptophytes

300	*Hydrocotyle himalaica* P.K. Mukh. 1969	Hyd_him	Araliaceae	Herbs	Dicot	Hemicryptophytes
301	*Hypericum hookerianum* Wight & Arn. 1834	Hyp_hoo	Hypericaceae	Shrub	Dicot	Phanerophytes
302	*Hypericum uralum* Buch. -Ham. ex D. Don 1823	Hyp_ura	Hypericaceae	Shrub	Dicot	Phanerophytes
303	*Ilex excelsa* (Wall.) Voigt 1845	Ile_exc	Aquifoliaceae	Tree	Dicot	Phanerophytes
304	*Impatiens scabrida* DC. 1824	Imp_sca	Boraginaceae	Herbs	Dicot	Therophytes
305	*Impatiens sulcata* Wall. 1824	Imp_sul	Boraginaceae	Herbs	Dicot	Therophytes
306	*Imperata cylindrica* (L.) Raeusch. 1797	Imp_cyl	Poaceae	Herbs	Monocot	Hemicryptophytes
307	*Indigofera atropurpurea* Buch. -Ham. ex Hornem. 1819	Ind_atr	Leguminosae	Shrub	Dicot	Phanerophytes
308	*Indigofera cassioides* Rottler ex DC. 1825	Ind_cas	Leguminosae	Shrub	Dicot	Phanerophytes
309	*Indigofera heterantha* Wall. ex Brandis 1874	Ind_het	Leguminosae	Shrub	Dicot	Phanerophytes
310	*Indigofera tinctoria* L. 1753	Ind_tin	Leguminosae	Shrub	Dicot	Phanerophytes
311	*Indopiptadenia oudhensis* (Brandis) Brenan 1955	Ind_oud	Leguminosae	Tree	Dicot	Phanerophytes
312	*Ipomoea cairica* (L.) Sweet 1826	Ipo_pen	Convolvulaceae	Climber	Dicot	Phanerophytes
313	*Ipomoea carnea* G.Forst. 1786	Ipo_car	Convolvulaceae	Herbs	Dicot	Chamaephytes
314	*Isachne albens* Trin. 1827	Isa_alb	Poaceae	Herbs	Monocot	Hemicryptophytes
315	*Isodon coetsa* (Buch. -Ham. ex D.Don) Kudô 1929	Iso_coe	Lamiaceae	Herbs	Dicot	Chamaephytes
316	*Jasminum mesnyi* Hance 1882	Jas_mes	Oleaceae	Shrub	Dicot	Phanerophytes
317	*Jasminum multiflorum* (Burm.f.) Andrews 1807	Jas_mul	Oleaceae	Shrub	Dicot	Phanerophytes
318	*Jasminum officinale* L. 1753	Jas_off	Oleaceae	Shrub	Dicot	Phanerophytes
319	*Jatropha curcas* L. 1753	Jat_cur	Euphorbiaceae	Shrub	Dicot	Phanerophytes
320	*Juglans regia* L. 1753	Jug-reg	Juglandaceae	Tree	Dicot	Phanerophytes
321	*Juniperus recurva* Buch. -Ham. ex D. Don 1825	Jun_rec	Cupressaceae	Tree	Gymnosperm	Phanerophytes
322	*Justicia adhatoda* L. 1753	Jus_adh	Acanthaceae	Shrub	Dicot	Phanerophytes
323	*Justicia diffusa* Willd. 1797	Jus_dif	Acanthaceae	Herbs	Dicot	Therophytes
324	*Justicia gendarussa* Burm. f. 1768	Jus_gen	Acanthaceae	Shrub	Dicot	Phanerophytes

325	*Justicia pubigera* (Nees) C. B. Clarke 1884	Jus_pub	Acanthaceae	Herbs	Dicot	Therophytes
326	*Justicia simplex* D. Don 1825	Jus_sim	Acanthaceae	Herbs	Dicot	Hemicryptophytes
327	*Kalanchoe pinnata* (Lam.) Pers. 1805	Kal_pin	Crassulaceae	Herbs	Dicot	Chamaephytes
328	*Kydia calycina* Roxb. 1819	Kyd_cal	Malvaceae	Tree	Dicot	Phanerophytes
329	*Kyllinga brevifolia* (Rottb.) Hassk. 1844	kyl_bre	Cyperaceae	Herbs	Monocot	Hemicryptophytes
330	*Lactuca dissecta* D. Don 1825	Lac_dis	Asteraceae	Herbs	Dicot	Therophytes
331	*Lagerstroemia parviflora* Roxb. 1796	Lag_par	Lythraceae	Tree	Dicot	Phanerophytes
332	*Laggera alata* (D. Don) Sch. Bip. ex Oliv. 1873	Lag_ala	Asteraceae	Herbs	Dicot	Therophytes
333	*Lannea coromandelica* (Houtt.) Merr. 1938	Lan_cor	Anacardiaceae	Tree	Dicot	Phanerophytes
334	*Lantana camara* L. 1753	Lan_cam	Verbenaceae	Shrub	Dicot	Phanerophytes
335	*Lathyrus aphaca* L. 1753	Lat_aph	Leguminosae	Herbs	Dicot	Therophytes
336	*Leea asiatica* (L.) Ridsdale 1980	Lee_asi	Vitaceae	shrub	Dicot	Phanerophytes
337	*Leersia hexandra* Sw. 1788	Lee-hex	Poaceae	Herbs	Monocot	Hemicryptophytes
338	*Lepidagathis incurva* Buch. -Ham. ex D. Don 1825	Lep_inc	Acanthaceae	Herbs	Dicot	Hemicryptophytes
339	*Lepisorus bicolor* (Takeda) Ching 1933	Lep_bic	Polypodiaceae	Ferns	Fern	Hemicryptophytes
340	*Lepisorus loriformis* (Wall. ex Mett.) Ching 1933	Lep_lor	Polypodiaceae	Ferns	Fern	Hemicryptophytes
341	*Lepisorus nudus* (Hook.) Ching 1933	Lep_nud	Polypodiaceae	Ferns	Fern	Hemicryptophytes
342	*Lepisorus scolopendrium* (Ching) Mehra & Bir 1964	Lep_sco	Polypodiaceae	Ferns	Fern	Hemicryptophytes
343	*Leptodesmia microphylla* (Thunb.) H.Ohashi & K.Ohashi 2018	Lep_mic	Leguminosae	Herbs	Dicot	Hemicryptophytes
344	*Leucaena leucocephala* (Lam.) de Wit 1961	Leu_leu	Lamiaceae	Tree	Dicot	Phanerophytes
345	*Leucas cephalotes* (Roth) Spreng. 1825	Leu_cep	Lamiaceae	Herbs	Dicot	Therophytes
346	*Leucas lanata* Benth. 1830	Leu_lan	Lamiaceae	Herbs	Dicot	Hemicryptophytes
347	*Lindenbergia grandiflora* (Buch. -Ham. ex D. Don) Benth. 1835	Lin_gra	Orobanchaceae	Herbs	Dicot	Therophytes

348	*Lindenbergia indica* (L.) Vatke 1875	Lin_ind	Orobanchaceae	Herbs	Dicot	Therophytes
349	*Lindera pulcherrima* (Nees) Benth. ex Hook.f. 1886	Lin_pul	Lauraceae	Tree	Dicot	Phanerophytes
350	*Lindernia nummulariifolia* (D. Don) Wettst. 1891	Lin_num	Linderniaceae	Herbs	Dicot	Therophytes
351	*Litsea monopetala* (Roxb.) Pers. 1806	Lit_mon	Lauraceae	Tree	Dicot	Phanerophytes
352	*Lobelia alsinoides* Lam. 1792	Lob_als	Campanulaceae	Herbs	Dicot	Therophytes
353	*Lonicera quinquelocularis* Hardw. 1799	Lon_qui	Caprifoliaceae	Shrub	Dicot	Phanerophytes
354	*Lophiolepis veruta* (D.Don) Bureš, Del Guacchio, Iamonico & P.Caputo 2022. Syn. *Cirsium verutum* (D. Don) Spreng. 1826)	Cir_ver	Asteraceae	Herbs	Dicot	Therophytes
355	*Luculia gratissima* (Wall.) Sweet 1826	Luc_gra	Rubiaceae	Shrub	Dicot	Phanerophytes
356	*Lycopodiella cernua* (L.) Pic. Serm. 1968	Lyc_cer	Lycopodiaceae	Ferns	Fern	Hemicryptophytes
357	*Lycopodium japonicum* Thunb. 1784	Lyc_jap	Lycopodiaceae	Ferns	Fern	Hemicryptophytes
358	*Lygodium flexuosum* (L.) Sw. 1801	Lyg_fle	Lygodiaceae	Ferns	Fern	Hemicryptophytes
359	*Lygodium japonicum* (Thunb.) Sw. 1801	Lyg_jap	Lygodiaceae	Ferns	Fern	Hemicryptophytes
360	*Lyonia ovalifolia* (Wall.) Drude 1939	Lyo_ova	Ericaceae	Tree	Dicot	Phanerophytes
361	*Macaranga denticulata* (Blume) Müll.Arg. 1866	Mac_den	Phyllanthaceae	Tree	Dicot	Phanerophytes
362	*Maclura cochinchinensis* (Lour.) Corner 1962	Mac_coc	Rosaceae	Shrub	Dicot	Phanerophytes
363	*Maesa chisia* Buch. -Ham. ex D. Don 1825	Mae_chi	Primulaceae	Tree	Dicot	Phanerophytes
364	*Mahonia napaulensis* DC. 1821 Syn. *Berberis napaulensis* (DC.) Spreng. 1825	Mah_nap	Berberidaceae	Shrub	Dicot	Phanerophytes
365	*Mallotus philippensis* (Lam.) Müll.Arg. 1865	Mal_phi	Euphorbiaceae	Tree	Dicot	Phanerophytes
366	*Mangifera indica* L. 1753	Man_ind	Anacardiaceae	Tree	Dicot	Phanerophytes
367	*Maoutia puya* (Hook.) Wedd. 1854	Mao_puy	Urticaceae	Shrub	Dicot	Phanerophytes
368	*Marsdenia roylei* Wight 1834	Mar_roy	Apocynaceae	Climber	Dicot	Phanerophytes
369	*Melanoseris macrorhiza* (Royle) N. Kilian 2011	Mel_mic	Asteraceae	Herbs	Dicot	Hemicryptophytes

370	*Melastoma malabathricum* L. 1753	Mel_mal	Melastomataceae	Shrub	Dicot	Phanerophytes
371	*Melia azedarach* L. 1753	Mel_aze	Meliaceae	Tree	Dicot	Phanerophytes
372	*Mentha arvensis* L. 1753	Men_arv	Lamiaceae	Herbs	Dicot	Hemicryptophytes
373	*Mesosphaerum suaveolens* (L.) Kuntze 1891	Mes_sua	Lamiaceae	Herbs	Dicot	Chamaephytes
374	*Micromeria biflora* (Buch. -Ham. ex D. Don) Benth. 1834	Mic_bif	Lamiaceae	Herbs	Dicot	Therophytes
375	*Microsorum membranaceum* (D. Don) Ching 1933	Mic_mem	Polypodiaceae	Ferns	Fern	Hemicryptophytes
376	*Millettia extensa* (Benth.) Benth. ex Baker 1876	Mil_ext	Leguminosae	Shrub	Dicot	Phanerophytes
377	*Mimosa pudica* L. 1753	Mim_pud	Leguminosae	Herbs	Dicot	Hemicryptophytes
378	*Mimosa rubicaulis* Lam. 1783	Mim_rub	Leguminosae	Shrub	Dicot	Phanerophytes
379	*Mucuna monosperma* Roxb. ex Wight 1831	Muc_mon	Leguminosae	Climber	Dicot	Phanerophytes
380	*Mucuna pruriens* (L.) DC. 1825	Muc_pru	Leguminosae	Climber	Dicot	Phanerophytes
381	*Murraya koenigii* (L.) Spreng. 1817	Mur_koe	Annonaceae	Tree	Dicot	Phanerophytes
382	*Mussaenda macrophylla* Wall. 1824	Mus_mac	Rubiaceae	Shrub	Dicot	Phanerophytes
383	*Mussaenda treutleri* Stapf 1909	Mus_tre	Rubiaceae	Shrub	Dicot	Phanerophytes
384	*Myrica esculenta* Buch. -Ham. ex D. Don 1825	Myr_esc	Rutaceae	Tree	Dicot	Phanerophytes
385	*Myrsine semiserrata* Wall. 1820	Myr_sem	Myrsinaceae	Tree	Dicot	Phanerophytes
386	*Nasturtium officinale* R.Br. 1812	Nas_off	Brassicaceae	Herbs	Dicot	Hemicryptophytes
387	*Nepeta elliptica* Royle ex Benth. 1833	Nep_ell	Lamiaceae	Herbs	Dicot	Chamaephytes
388	*Nephrolepis cordifolia* (L.) C. Presl 1836	Nep_cor	Nephrolepidaceae	Ferns	Fern	Hemicryptophytes
389	*Nicandra physalodes* (L.) Gaertn. 1791	Nic_phy	Solanaceae	Herbs	Dicot	Therophytes
390	*Nyctanthes arbor-tristis* L. 1753	Nyc_arb	Oleaceae	Tree	Dicot	Phanerophytes
391	*Oberonia ensiformis* (Sm.) Lindl. 1859	Obe_ens	Orchidaceae	Herbs	Monocot	Phanerophytes
392	*Oberonia falconeri* Hook.f. 1888	Obe_fal	Orchidaceae	Herbs	Monocot	Phanerophytes
393	*Ocimum gratissimum* L. 1753	Oci_gra	Lamiaceae	Herbs	Dicot	Chamaephytes
394	*Odontosoria chinensis* (L.) J. Sm. 1857	Odo_chi	Lindsaeaceae	Ferns	Fern	Hemicryptophytes

395	*Oleandra wallichii* (Hook.) C. Presl 1836	Ole_wal	Oleandraceae	Ferns	Fern	Hemicryptophytes
396	*Onychium cryptogrammoides* Christ 1909	Ony_cry	Pteridaceae	Ferns	Fern	Hemicryptophytes
397	*Onychium siliculosum* (Desv.) C. Chr. 1905	Ony_sil	Pteridaceae	Ferns	Fern	Hemicryptophytes
398	*Onychium lucidum* (D. Don) Spreng. 1827	Ony_luc	Pteridaceae	Ferns	Fern	Hemicryptophytes
399	*Ophiorrhiza fasciculata* D.Don 1825	Oph_fas	Rubiaceae	Herbs	Dicot	Chamaephytes
400	*Opuntia monacanthos* (Willd.) Haw. 1819	Opu_mon	Cactaceae	Shrub	Dicot	Phanerophytes
401	*Oroxylum indicum* (L.) Kurz 1877	Oro_ind	Bignoniaceae	Tree	Dicot	Phanerophytes
402	*Osbeckia nepalensis* Hook. 1822	Osb_nep	Melastomataceae	Shrub	Dicot	Phanerophytes
403	*Osbeckia stellata* Buch. -Ham. ex D. Don 1822	Osb_ste	Melastomataceae	Shrub	Dicot	Phanerophytes
404	*Osyris wightiana* J.Graham 1839	Osy_wig	Santalaceae	Shrub	Dicot	Phanerophytes
405	*Ototropis multiflora* (DC.) H.Ohashi & K.Ohashi 2012	Oto_mul	Leguminosae	Shrub	Dicot	Phanerophytes
406	*Ougeinia oojeinensis* (Roxb.) Hochr. 1909	Oug_ooj	Leguminosae	Tree	Dicot	Phanerophytes
407	*Oxalis corniculata* L. 1753	Oxa_cor	Oxalidaceae	Herbs	Dicot	Geophytes
408	*Oxalis latifolia* Kunth 1822	Oxa_lat	Oxalidaceae	Herbs	Dicot	Geophytes
409	*Pandanus furcatus* Roxb. 1814	Pan_nep	Pandanaceae	Shrub	Monocot	Phanerophytes
410	*Panicum repens* L. 1753	Pan_rep	Poaceae	Herbs	Monocot	Hemicryptophytes
411	*Papilionanthe uniflora* (Lindl.) Garay 1974	Pap_uni	Orchidaceae	Herbs	Monocot	Phanerophytes
412	*Parthenium hysterophorus* L. 1753	Par_hys	Asteraceae	Herbs	Dicot	Therophytes
413	*Paspalum distichum* L. 1759	Pas_dis	Poaceae	Herbs	Monocot	Hemicryptophytes
414	*Paspalum scrobiculatum* L. 1767	Pas_scr	Poaceae	Herbs	Monocot	Hemicryptophytes
415	*Pedicularis bifida* (Buch. -Ham.) Pennell 1943	Ped_bif	Orobanchaceae	Herbs	Dicot	Therophytes
416	*Pennisetum flaccidum* Griseb. 1868 Syn. *Cenchrus flaccidus* (Griseb.) Morrone 2010	Pen_fla	Poaceae	Herbs	Monocot	Hemicryptophytes
417	*Peperomia tetraphylla* (G. Forst.) Hook. & Arn. 1832	Pep_tet	Piperaceae	Herbs	Dicot	Hemicryptophytes

418	*Persea odoratissima* (Nees) Kosterm. 1942 Syn. *Machilus odoratissimus* Nees 1831	Per_odo	Lauraceae	Tree	Dicot	Phanerophytes
419	*Persicaria barbata* (L.) H. Hara 1966	Per_bar	Polygonaceae	Herbs	Dicot	Geophytes
420	*Persicaria capitata* (Buch. -Ham. ex D. Don) H. Gross 1913	Per_cap	Polygonaceae	Herbs	Dicot	Geophytes
421	*Persicaria chinensis* (L.) H.Gross 1913	Per_chi	Polygonaceae	Herbs	Dicot	Geophytes
422	*Persicaria hydropiper* (L.) Delarbre 1800	Per_hyd	Polygonaceae	Herbs	Dicot	Geophytes
423	*Persicaria nepalensis* (Meisn.) H. Gross 1913	Per_nep	Polygonaceae	Herbs	Dicot	Geophytes
424	*Phlogacanthus pubinervius* T. Anderson 1867	Phl_pub	Acanthaceae	Shrub	Dicot	Phanerophytes
425	*Phoebe lanceolata* (Nees) Nees 1836	Pho_lan	Lauraceae	Tree	Dicot	Phanerophytes
426	*Phoenix acaulis* Roxb. 1820	Pho_fla	Poaceae	Herbs	Monocot	Geophytes
427	*Phoenix loureiroi* Kunth 1841	Pho_lou	Arecaceae	Shrub	Monocot	Phanerophytes
428	*Phragmites karka* (Retz.) Trin. ex Steud. 1841	Phr_kar	Arecaceae	Shrub	Monocot	Phanerophytes
429	*Phyllanthus emblica* L. 1753	Phy_emb	Phyllanthaceae	Tree	Dicot	Phanerophytes
430	*Phyllanthus parvifolius* Buch. -Ham. ex D.Don 1825	Phy_par	Phyllanthaceae	Shrub	Dicot	Phanerophytes
431	*Phyllanthus urinaria* L. 1753	Phy_uri	Phyllanthaceae	Herbs	Dicot	Therophytes
432	*Pilea scripta* (Buch. -Ham. ex D. Don) Wedd. 1854	Pil_scr	Urticaceae	Herbs	Dicot	Chamaephytes
433	*Pilea umbrosa* Wedd. ex Blume 1856	Pil_umb	Urticaceae	Herbs	Dicot	Chamaephytes
434	*Pinus patula* Schiede ex Schltdl. & Cham.1831	Pin_pat	Pinaceae	Tree	Gymnosperm	Phanerophytes
435	*Pinus roxburghii* Sarg. 1897	Pin_rox	Pinaceae	Tree	Gymnosperm	Phanerophytes
436	*Pinus wallichiana* A.B. Jacks. 1938	Pin_wal	Pinaceae	Tree	Gymnosperm	Phanerophytes
437	*Piper mullesua* Buch. -Ham. ex D. Don 1825 Syn. *Piper peepuloides* Roxb. 1820	Pip_mul	Piperaceae	Climber	Dicot	Phanerophytes
438	*Plantago major* L. 1753	Pla_maj	Lamiaceae	Herbs	Dicot	Geophytes
439	*Platostoma coloratum* (D.Don) A.J.Paton 1997	Pla_col	Plantaginaceae	Herbs	Dicot	Therophytes

440	*Pleurolobus gangeticus* (L.) J.St.-Hil. ex H.Ohashi & K.Ohashi 2018	Ple_gan	Leguminosae	Shrub	Dicot	Phanerophytes
441	*Pogostemon benghalensis* (Burm.f.) Kuntze 1891	Pog_ben	Lamiaceae	Shrub	Dicot	Phanerophytes
442	*Polygonatum punctatum* Royle ex Kunth 1850	Pol_pun	Asparagaceae	Herbs	Monocot	Geophytes
443	*Polystichum discretum* (D. Don) J. Sm. 1841	Pol_dis	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
444	*Polystichum obliquum* (D. Don) T. Moore 1858	Pol_obl	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
445	*Polystichum squarrosum* (D. Don) Fée 1852	Pol_squ	Dryopteridaceae	Ferns	Fern	Hemicryptophytes
446	*Poranopsis paniculata* (Roxb.) Roberty 1952	Por_pan	Convolvulaceae	Shrub	Dicot	Phanerophytes
447	*Portulaca oleracea* L. 1753	Por_ole	Portulacaceae	Herbs	Dicot	Therophytes
448	*Pouzolzia rugulosa* (Wedd.) Acharya & Kravtsova 2009	Pou_rug	Urticaceae	Tree	Dicot	Phanerophytes
449	*Premna barbata* Wall. ex Schauer 1847	Pre_bar	Lamiaceae	Tree	Dicot	Phanerophytes
450	*Prunus cerasoides* Buch.-Ham. ex D.Don 1825	Pru_cer	Rosaceae	Tree	Dicot	Phanerophytes
451	*Pseudognaphalium affine* (D. Don) Anderb.1991	Pse_aff	Asteraceae	Herbs	Dicot	Therophytes
452	*Pteridium revolutum* (Blume) Nakai 1925	Pte_rev	Dennstaediaceae	Ferns	Fern	Hemicryptophytes
453	*Pteris aspericaulis* Wall. ex J. Agardh 1839	Pte_asp	Pteridaceae	Ferns	Fern	Hemicryptophytes
454	*Pteris biaurita* L 1753	Pte_bia	Pteridaceae	Ferns	Fern	Hemicryptophytes
455	*Pteris cretica* subsp. *laeta* (Wall. ex Ettingsh.) Fraser-Jenk.2008	Pte_cre	Pteridaceae	Ferns	Fern	Hemicryptophytes
456	*Pteris subquinata* Wall. ex J.Agardh 1839	Pte_sub	Pteridaceae	Ferns	Fern	Hemicryptophytes
457	*Pteris vittata* L. 1753	Pte_vit	Pteridaceae	Ferns	Fern	Hemicryptophytes
458	*Pteris wallichiana* J. Agardh 1839	Pte_wal	Pteridaceae	Ferns	Fern	Hemicryptophytes
459	*Pyracantha crenulata* (D. Don) M. Roem. 1847	Pyr_cre	Rosaceae	Shrub	Dicot	Phanerophytes
460	*Pyrrosia flocculosa* (D. Don) Ching 1935	Pyr_flo	Polypodiaceae	Ferns	Fern	Hemicryptophytes
461	*Pyrrosia porosa* (C. Presl) Hovenkamp 1984	Pyr_por	Polypodiaceae	Ferns	Fern	Hemicryptophytes
462	*Pyrus pashia* Buch. -Ham. ex D. Don 1825	Pyr_pas	Rosaceae	Tree	Dicot	Phanerophytes
463	*Quercus glauca* Thunb. 1784	Que_gla	Fagaceae	Tree	Dicot	Phanerophytes

464	*Quercus lanata* Sm. 1814	Que_lan	Fagaceae	Tree	Dicot	Phanerophytes
465	*Quercus leucotrichophora* A.Camus 1935	Que_leu	Fagaceae	Tree	Dicot	Phanerophytes
466	*Quercus semecarpifolia* Sm. 1814	Que_sem	Fagaceae	Tree	Dicot	Phanerophytes
467	*Ranunculus sceleratus* L. 1753	Ran_scl	Ranunculaceae	Herbs	Dicot	Therophytes
468	*Reinwardtia indica* Dumort. 1822	Rei_ind	Linaceae	Shrub	Dicot	Phanerophytes
469	*Remusatia vivipara* (Roxb.) Schott 1832	Rem_viv	Araceae	Herbs	Monocot	Geophytes
470	*Rhaphidophora glauca* (Wall.) Schott 1857	Rha_gla	Araceae	Herbs	Monocot	Geophytes
471	*Rhododendron arboreum* Sm. 1805	Rho_arb	Ericaceae	Tree	Dicot	Phanerophytes
472	*Rhus javanica* L. 1753 Syn. Brucea javanica (L.) Merr. 1928	Rhu_jav	Anacardiaceae	Tree	Dicot	Phanerophytes
473	*Rhynchoglossum obliquum* Blume 1826	Rhy_obl	Gesneriaceae	Herbs	Dicot	Therophytes
474	*Rhynchostylis retusa* (L.) Blume 1825	Rhy_ret	Orchidaceae	Herbs	Monocot	Phanerophytes
475	*Rosa brunonii* Lindl. 1820	Ros_bru	Rosaceae	Shrub	Dicot	Phanerophytes
476	*Roylea cinerea* (D. Don) Baill. 1891	Roy_cin	Lamiaceae	Herbs	Dicot	Chamaephytes
477	*Rubia manjith* Roxb.1810	Rub_man	Rubiaceae	Climber	Dicot	Phanerophytes
478	*Rubus acuminatus* Sm. 1815	Rub_acu	Rosaceae	Shrub	Dicot	Phanerophytes
479	*Rubus ellipticus* Sm. 1815	Rub_ell	Rosaceae	Shrub	Dicot	Phanerophytes
480	*Rubus paniculatus* Sm. 1815	Rub_pan	Rosaceae	Shrub	Dicot	Phanerophytes
481	*Rubus rugosus* Jensen ex Lange 1877	Rub_rug	Rosaceae	Shrub	Dicot	Phanerophytes
482	*Rumex hastatus* D. Don 1825	Rum_has	Polygonaceae	Herbs	Dicot	Chamaephytes
483	*Rumex nepalensis* Spreng. 1825	Rum_nep	Polygonaceae	Herbs	Dicot	Geophytes
484	*Rungia pectinata* (L.) Nees 1847	Run_pec	Acanthaceae	Herbs	Dicot	Therophytes
485	*Saccharum spontaneum* L. 1771	Sac_spo	Poaceae	Herbs	Monocot	Hemicryptophytes
486	*Sagittaria trifolia* L. 1753	Sag_tri	Alismataceae	Herbs	Monocot	Geophytes
487	*Salix babylonica* L. 1753	Sal_bab	Salicaceae	Tree	Dicot	Phanerophytes
488	*Salvia splendens* Sellow ex Nees 1821	Sal_spl	Lamiaceae	Herbs	Dicot	Therophytes

489	*Sarcococca coriacea* (Hook.) Sweet 1826	Sar_cor	Buxaceae	Tree	Dicot	Phanerophytes
490	*Sarcococca hookeriana* Baill. 1859	Sar_hoo	Buxaceae	Shrub	Dicot	Phanerophytes
491	*Satyrium nepalense* D.Don 1825	Sat_nep	Orchidaceae	Herbs	Monocot	Geophytes
492	*Saurauia napaulensis* DC 1822	Sau_nap	Actinidiaceae	Tree	Dicot	Phanerophytes
493	*Schefflera venulosa* (Wight & Arn.) Harms 1894. Syn. *Heptapleurum venulosum* (Wight & Arn.) Seem. 1865	Sch_ven	Araliaceae	Shrub	Dicot	Phanerophytes
494	*Schima wallichii* (DC.) Korth. 1842	Sch_wal	Theaceae	Tree	Dicot	Phanerophytes
495	*Schoenoplectiella juncoides* (Roxb.) Lye 2003	Sat_jun	Cyperaceae	Herbs	Monocot	Hemicryptophytes
496	*Scurrula parasitica* L. 1753	Scu_par	Loranthaceae	shrub	Dicot	Phanerophytes
497	*Scutellaria discolor* Wall. ex Benth. 1830	Scu_dis	Lamiaceae	Herbs	Dicot	Geophytes
498	*Scutellaria scandens* D.Don 1825	Scu_sca	Lamiaceae	Herbs	Dicot	Geophytes
499	*Searsia parviflora* (Roxb.) F. A. Barkley 1950	Sea_par	Anacardiaceae	Shrub	Dicot	Phanerophytes
500	*Selaginella fulcrata* (Buch. -Ham. ex D. Don) Spring 1843	Sel_ful	Selaginaceae	Ferns	Fern	Hemicryptophytes
501	*Selaginella pallida* Spring 1843	Sel_pal	Selaginaceae	Ferns	Fern	Hemicryptophytes
502	*Selaginella subdiaphana* (Wall. ex Hook. & Grev.) Spring 1843	Sel_sub	Selaginaceae	Ferns	Fern	Hemicryptophytes
503	*Selaginella vaginata* Spring 1850	Sel_vag	Selaginaceae	Ferns	Fern	Hemicryptophytes
504	*Selinum wallichianum* (DC.) Raizada & H.O. Saxena 1966	Sel_wal	Apiaceae	Shrub	Dicot	Phanerophytes
505	*Selliguea capitellata* (Wall.) X. C. Zhang & L. J. He 2018	Sel_cap	Polypodiaceae	Ferns	Fern	Hemicryptophytes
506	*Selliguea oxyloba* (Wall. ex Kunze) Fraser-Jenk. 2008	Sel_oxy	Polypodiaceae	Ferns	Fern	Hemicryptophytes
507	*Semecarpus anacardium* L. f. 1782	Sem_ana	Anacardiaceae	Tree	Dicot	Phanerophytes
508	*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb. 2008	Sen_cat	Leguminosae	Tree	Dicot	Phanerophytes

509	*Senna occidentalis* (L.) Link 1831	Sen_occ	Leguminosae	Herbs	Dicot	Chamaephytes
510	*Senna sophera* (L.) Roxb. 1832	Sen_sop	Leguminosae	Herbs	Dicot	Chamaephytes
511	*Senna tora* (L.) Roxb 1832	Sen_tor	Leguminosae	Herbs	Dicot	Therophytes
512	*Setaria parviflora* (Poir.) Kerguélen 1987	Set_par	Poaceae	Herbs	Monocot	Hemicryptophytes
513	*Setaria pumila* (Poir.) Roem. & Schult.1817	Set_pum	Poaceae	Herbs	Monocot	Hemicryptophytes
514	*Setaria punctata* (Burm.f.) Veldkamp 1994	Pap_pun	Poaceae	Herbs	Monocot	Hemicryptophytes
515	*Shorea robusta* C.F.Gaertn. 1805	Sho_rob	Dipterocarpaceae	Tree	Dicot	Phanerophytes
516	*Sida cordata* (Burm.f.) Borss.Waalk.1966	Sid_cor	Malvaceae	Herbs	Dicot	Chamaephytes
517	*Sida cordifolia* L. 1753	Sid_cor	Malvaceae	Herbs	Dicot	Chamaephytes
518	*Sida rhombifolia* L. 1753	Sid_rho	Malvaceae	Herbs	Dicot	Chamaephytes
519	*Sigesbeckia orientalis* L. 1753	Sie_ori	Asteraceae	Herbs	Dicot	Therophytes
520	*Smilax aspera* L. 1753	Smi_asp	Smilacaceae	Climber	Monocot	Phanerophytes
521	*Smilax lanceifolia* Roxb. 1832	Smi_lan	Smilacaceae	Climber	Monocot	Phanerophytes
522	*Smilax ovalifolia* Roxb. ex D.Don 1825 Syn. *Smilax zeylanica* L. 1753	Smi_ova	Smilacaceae	Climber	Monocot	Phanerophytes
523	*Smilax perfoliata* Lour. 1790	Smi_per	Smilacaceae	Climber	Monocot	Phanerophytes
524	*Sohmaea laxiflora* (DC.) H.Ohashi & K.Ohashi 2018	Soh_lax	Leguminosae	Herbs	Dicot	Chamaephytes
525	*Solanum aculeatissimum* Jacq. 1781	Sol_acu	Solanaceae	Shrub	Dicot	Chamaephytes
526	*Solanum nigrum* L. 1753	Sol_nig	Solanaceae	Herbs	Dicot	Therophytes
527	*Solanum virginianum* L. 1753	Sol_vir	Solanaceae	Herbs	Dicot	Chamaephytes
528	*Solena amplexicaulis* (Lam.) Gandhi 1776	Sol_amp	Cucurbittaceae	Climber	Dicot	Phanerophytes
529	*Sonchus asper* (L.) Hill 1769	Son_asp	Asteraceae	Herbs	Dicot	Therophytes
530	*Spatholobus parviflorus* (Roxb. ex G.Don) Kuntze 1891	Spa_par	Leguminosae	Shrub	Dicot	Phanerophytes
531	*Spermadictyon suaveolens* Roxb. 1815	Spe_sua	Rubiaceae	Shrub	Dicot	Phanerophytes
532	*Spondias pinnata* (L. f.) Kurz 1875	Spo_pin	Anacardiaceae	Tree	Dicot	Phanerophytes

533	*Sporobolus diandrus* (Retz.) P. Beauv. 1812	Spo_dia	Poaceae	Herbs	Monocot	Hemicryptophytes
534	*Stephanotis volubilis* (L. f.) S. Reuss, Liede & Meve 2022	Ste_vol	Apocynaceae	Shrub	Dicot	Phanerophytes
535	*Sterculia villosa* Roxb. ex Sm. 1816	Ste_vil	Malvaceae	Tree	Dicot	Phanerophytes
536	*Strobilanthes angustifrons* C. B. Clarke 1884	Str_ang	Acanthaceae	Herbs	Dicot	Therophytes
537	*Strobilanthes attenuata* (Wall. ex Nees) Jacq. ex Nees 1847	Str_att	Acanthaceae	Herbs	Dicot	Therophytes
538	*Strobilanthes auriculata* Nees 1832	Str_aur	Acanthaceae	Herbs	Dicot	Therophytes
539	*Strobilanthes capitata* (Nees) T. Anderson 1867	Str_cap	Acanthaceae	Herbs	Dicot	Therophytes
540	*Strobilanthes hamiltoniana* (Steud.) Bosser & Heine 1988	str_ham	Acanthaceae	Herbs	Dicot	Chamaephytes
541	*Strobilanthes nutans* (Nees) T. Anderson 1867	Str_nut	Acanthaceae	Herbs	Dicot	Therophytes
542	*Strobilanthes tomentosa* (Nees) J. R. I. Wood 2009	Str_tom	Acanthaceae	Herbs	Dicot	Chamaephytes
543	*Strobilanthes wallichii* Nees 1832	Str_wal	Acanthaceae	Herbs	Dicot	Chamaephytes
544	*Sunhangia elegans* (DC.) H.Ohashi & K.Ohashi 2019	Sun_ele	Leguminosae	Shrub	Dicot	Phanerophytes
545	*Swertia angustifolia* Buch. -Ham. ex D. Don 1825	Swe_ang	Gentianaceae	Herbs	Dicot	Therophytes
546	*Swertia nervosa* (Wall. ex G. Don) C. B. Clarke 1883	Swe_ner	Gentianaceae	Herbs	Dicot	Therophytes
547	*Swertia paniculata* Wall. 1831	Swe_pan	Gentianaceae	Herbs	Dicot	Therophytes
548	*Syzygium cumini* (L.) Skeels 1912	Syz_cum	Myrtaceae	Tree	Dicot	Phanerophytes
549	*Syzygium nervosum* DC. 1828	Syz_ner	Myrtaceae	Tree	Dicot	Phanerophytes
550	*Tateishia concinna* (DC.) H.Ohashi & K.Ohashi 2018	Tat_con	Leguminosae	Shrub	Dicot	Phanerophytes
551	*Tectaria coadunata* (J.Sm.) C.Chr. 1931	Tec_coa	Tectariaceae	Ferns	Fern	Hemicryptophytes
552	*Tectaria gemmifera* (Fée) Alston 1939	Tec_gem	Tectariaceae	Ferns	Fern	Hemicryptophytes
553	*Terminalia bellirica* (Gaertn.) Roxb. 1805	Ter_bel	Combretaceae	Tree	Dicot	Phanerophytes

554	*Terminalia chebula* Retz. 1788	Ter_che	Combretaceae	Tree	Dicot	Phanerophytes
555	*Terminalia elliptica* Willd. 1806	Ter_tom	Combretaceae	Tree	Dicot	Phanerophytes
556	*Tetrastigma serrulatum* (Roxb.) Planch. 1887	Tet_ser	Vitaceae	Climber	Dicot	Phanerophytes
557	*Teucrium quadrifarium* Buch. -Ham. ex D.Don 1825	Teu_qua	Lamiaceae	Herbs	Dicot	Hemicryptophytes
558	*Thelypteris arida* (D.Don) C.V.Morton 1959	The_ari	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
559	*Thelypteris cana* (Baker) Ching 1936	The_can	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
560	*Thelypteris clarkei* (Bedd.) C.F.Reed 1968	The_cla	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
561	*Thelypteris dentata* (Forssk.) E.P.St.John 1936	The_den	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
562	*Thelypteris glanduligera* (Kunze) Ching 1936	The_gla	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
563	*Thelypteris nudata* (Roxb.) C.V. Morton 1974	The_nud	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
564	*Thelypteris procera* (D.Don) Fraser-Jenk. 2008	The_pro	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
565	*Thelypteris prolifera* (Retz.) C.F.Reed 1968	The_pro	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
566	*Thelypteris tylodes* (Kunze) Ching 1936	The_tyl	Thelypteridaceae	Ferns	Fern	Hemicryptophytes
567	*Themeda villosa* (Lam.) A.Camus 1922	The_vil	Poaceae	Herbs	Monocot	Hemicryptophytes
568	*Thespesia lampas* (Cav.) Dalzell & A. Gibson 1861 Syn. *Azanza lampas* (Cav.) Alef. 1861	The_lam	Malvaceae	Shrub	Dicot	Chamaephytes
569	*Thunbergia coccinea* Wall. ex D.Don 1825	Thu_coc	Ranunculaceae	Climber	Dicot	Phanerophytes
570	*Thunbergia fragrans* Roxb. 1796	Thu_fra	Ranunculaceae	Climber	Dicot	Phanerophytes
571	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda 1930	Thy_max	Poaceae	Herbs	Monocot	Geophytes
572	*Tinospora sinensis* (Lour.) Merr. 1934	Tin_sin	Menispermaceae	Climber	Dicot	Phanerophytes
573	*Toona ciliata* M. Roem. 1846	Too_cil	Meliaceae	Tree	Dicot	Phanerophytes
574	*Torenia cordifolia* Roxb. 1805	Tor_cor	Linderniaceae	Herbs	Dicot	Therophytes
575	*Trema cannabina* Lour. 1790	Tre_can	Cannabaceae	Shrub	Dicot	Phanerophytes
576	*Trema tomentosa* (Roxb.) H. Hara 1971	Tre_tom	Cannabaceae	Shrub	Dicot	Phanerophytes

577	*Trichosanthes wallichiana* (Ser.) Wight 1842	Tri_wal	Cucurbittaceae	Climber	Dicot	Phanerophytes
578	*Tridax procumbens* L. 1753	Tri_pro	Asteraceae	Herbs	Dicot	Hemicryptophytes
579	*Trifolium repens* L. 1753	Tri_rep	Leguminosae	Herbs	Dicot	Hemicryptophytes
580	*Triumfetta annua* L. 1767	Tri_ann	Urticaceae	Herbs	Dicot	Chamaephytes
581	*Triumfetta rhomboidea* Jacq. 1760	Tri_rho	Malvaceae	Shrub	Dicot	Phanerophytes
582	*Typha angustifolia* L. 1753	Typ_ang	Typhaceae	Herbs	Monocot	Geophytes
583	*Urena lobata* L. 1753	Ure_lob	Malvaceae	Shrub	Dicot	Phanerophytes
584	*Urtica ardens* Link 1822	Urt_ard	Urticaceae	Herbs	Dicot	Hemicryptophytes
585	*Urtica dioica* L. 1953	Urt_dio	Urticaceae	Herbs	Dicot	Hemicryptophytes
586	*Vanda tessellata* (Roxb.) Hook. ex G.Don 1830	Van_rox	Orchidaceae	Herbs	Monocot	Phanerophytes
587	*Veronica persica* Poir. 1808	Ver_per	Plantaginaceae	Herbs	Dicot	Therophytes
588	*Viburnum cylindricum* Buch. -Ham. ex D. Don 1825	Vib_cyl	Adoxaceae	Shrub	Dicot	Phanerophytes
589	*Viburnum mullaha* Buch. -Ham. ex D. Don 1825	Vib_mul	Adoxaceae	Shrub	Dicot	Phanerophytes
590	*Vicia angustifolia* L. 1759	Vic_ang	Leguminosae	Herbs	Dicot	Therophytes
591	*Vicia hirsuta* (L.) Gray 1822	Vic_hir	Leguminosae	Herbs	Dicot	Therophytes
592	*Viscum monoicum* Roxb. ex DC. 1830	Vis_mon	Santalaceae	Shrub	Dicot	Phanerophytes
593	*Vitex negundo* L.1753	Vit_neg	Lamiaceae	Shrub	Dicot	Phanerophytes
594	*Vittaria linearifolia* Ching 1931 Syn. *Haplopteris mediosora* (Hayata) X.C.Zhang 2003	Vit_lin	Pteridaceae	Ferns	Fern	Hemicryptophytes
595	*Wendlandia coriacea* (Wall.) DC. 1830	Wen_cor	Rubiaceae	Tree	Dicot	Phanerophytes
596	*Wendlandia heynei* (Schult.) Santapau & Merchant 1862	Wen_hey	Rubiaceae	Tree	Dicot	Phanerophytes
597	*Wikstroemia canescens* Meisn. 1841	Wik_can	Thymelaeaceae	Shrub	Dicot	Phanerophytes
598	*Woodfordia fruticosa* (L.) Kurz 1871	Woo_fru	Lythraceae	Shrub	Dicot	Phanerophytes
599	*Woodwardia unigemmata* (Makino) Nakai 1925	Woo_uni	Blechnaceae	Ferns	Fern	Hemicryptophytes

600	*Xanthium strumarium* L. 1753	Xan_str	Asteraceae	Herbs	Dicot	Chamaephytes
601	*Xylosma longifolia* Clos 1857	Xyl_lon	Salicaceae	Tree	Dicot	Phanerophytes
602	*Yua thomsonii* (M. A. Lawson) C. L. Li 1990	Yua_tho	Vitaceae	Climber	Dicot	Phanerophytes
603	*Zanthoxylum armatum* DC. 1824	Zan_arm	Rutaceae	Tree	Dicot	Phanerophytes
604	*Zanthoxylum oxyphyllum* Edgew 1846	Zan_arm	Rutaceae	Tree	Dicot	Phanerophytes
605	*Ziziphus incurva* Roxb. 1824	Ziz_inc	Rhamnaceae	Shrub	Dicot	Phanerophytes
606	*Ziziphus mauritiana* Lam. 1789	Ziz_mau	Rhamnaceae	Shrub	Dicot	Phanerophytes

Annex 3: Species richness of different forest types

Forest types	***Shorea***	**Grassland**	**Mixed Conifer**	**Mixed Pine**	**Quercus-Rhohodendron**
Species richness	305	165	365	390	240

Annex 4. The IVI value of dominant species of life forms according to ecological regions

Phanerophyte species	**Ecological regions**	**Quantitative parameter**				**Chamaephyte species**	**Ecological region**	**Quantitative parameters**			
		RD	**RF**	**RC**	**IVI**			**RD**	**RF**	**RC**	**IVI**
Shorea robusta	Tropical	13.85	3.03	62.67	79.56	*Inula cappa*	Tropical	13.19	11.49	11.04	35.69
Diploknema butyracea	Tropical	11.72	2.1	5.84	19.66	*Sida cordata*	Tropical	2.42	9.25	10.49	22.16
Reinwardtia indica	Tropical	11.85	1.52	1.56	14.93	*Achyranthes aspera*	Tropical	11.58	8.21	2.37	22.15
Cissampelos pareira	Tropical	1.56	2.68	0.56	4.8	*Rumex hastatus*	Tropical	7.67	7.29	7.05	22.01
Schima wallichii	Tropical	1.59	2.57	5.08	9.23	*Artemisia indica*	Tropical	14.27	4.25	3.34	21.86
Phyllanthus parvifolius	Tropical	2.39	1.17	0.44		*Xanthium*	Tropical	2.69	8.33	8.24	19.27

						stramonium					
Pinus roxburghii	Sub-tropical	6.86	2.51	18.92	28.29	*Sida rhombifolia*	Tropical	2.56	5.21	8.37	16.14
Reinwardtia indica	Sub-tropical	25.42	1.69	1.02	27.11	*Rumex hastatus*	Sub-tropical	11.25	11.25	11.16	33.66
Shorea robusta	Sub-tropical	9.82	1.11	14.85	25.78	*Inula cappa*	Sub-tropical	6.67	6.67	6.61	19.94
Schima wallichii	Sub-tropical	3.97	2.17	16.77	22.91	*Ocimum gratissimum*	Sub-tropical	5.83	5.83	5.79	17.45
Phyllanthus parvifolius	Sub-tropical	12.35	1.35	1.01	14.71	*Achyranthes aspera*	Sub-tropical	5.42	5.42	5.37	16.21
Rhododendron arboreum	Sub-tropical	4.56	2.32	4.7	11.58	*Dipsacus inermis*	Sub-tropical	5.42	5.42	5.37	16.21
Lyonia ovalifolia	Sub-tropical	3.87	2.41	2.05	8.33	*Isodon coesta*	Sub-tropical	5	5	4.96	14.96
Rhododendron arboreum	Temperate	5.36	0	27.52	32.88	*Girardinia diversifolia*	Sub-tropical	4.58	4.58	4.55	13.71
Eurya acuminata	Temperate	3.61	0.04	13.77	17.41	*Rumex hastatus*	Temperate	30	31.25	31.25	92.5
Myrica esculenta	Temperate	3.61	0.04	6.53	10.18	*Dipsacus inermis*	Temperate	9.33	25	25	59.33
Lyonia ovalifolia	Temperate	3.92	0.04	5.12	9.07	*Strobilanthes hamiltoniana*	Temperate	22.67	12.5	12.5	47.67
Alnus nepalensis	Temperate	0.72	1.1	6.05	7.88	*Anisomeles indica*	Temperate	2	6.25	6.25	14.5
Quercus lanata	Temperate	2.75	0.02	4.93	7.7	*Clinopodium umbrosum*	Temperate	10	6.25	6.25	22.5
Berberis asiatca	Temperate	4.33	0.04	3.15	7.52	*Girardinia diversifolia*	Temperate	4.67	6.25	6.25	17.17

Hemicryptophyte species	**Ecological regions**	**Quantitative parameters**				**Geophyte species**	**Ecological regions**	**Quantitative parameters**			
		RD	**RF**	**RC**	**IVI**			**RD**	**RF**	**RC**	**IVI**
Saccharum spontaneum	Tropical	13.37	3.76	9.31	26.44	*Capillipedium assimile*	Tropical	64.73	21.09	52.51	138.33
Imperata cylindrica	Tropical	8.63	3.18	6.87	18.69	*Brachiaria villosa*	Tropical	10.35	7.03	1.34	18.72
Cynodon dactylon	Tropical	5.84	2.02	2.66	10.53	*Oxalis corniculata*	Tropical	6.04	8.59	4.01	18.65
Adiantum philippense	Tropical	3.15	3.47	3.77	10.39	*Persicaria barbat*	Tropical	3.22	7.81	3.34	14.38
Cymbopogon pendulus	Tropical	2.82	3.76	3.77	10.34	*Cyperus rotundus*	Tropical	2.64	6.25	2.68	11.57
Digitaria ciliaris	Tropical	4.54	1.16	4.21	9.91	*Cheilocostus speciosus*	Tropical	0.71	7.03	3.01	10.75
Erioscirpus comosus	Tropical	1.58	3.76	2.88	8.22	*Capillipedium assimile*	Sub-tropical	59.32	18.54	41.24	119.1
Cynodon dactylon	Sub-trop	12.54	2.74	8.47	23.74	*Oxalis corniculata*	Sub-tropical	9.8	10.26	5.25	25.32
Imperata cylindrica	Sub-trop	10.24	3.52	8.67	22.43	*Brachiaria villosa*	Sub-tropical	8.62	4.3	3.55	16.48
Centella asiatica	Sub-trop	4.37	3.39	3.59	11.35	*Arisaema tortuosum*	Sub-tropical	0.4	6.62	4.02	11.04
Cymbopogon pendulus	Sub-trop	4.58	3.39	3.19	11.16	*Persicaria barbata*	Sub-tropical	2.71	5.3	2.47	10.48
Chrysopogon aciculatus	Sub-trop	4.65	2.09	3.59	10.32	*Cyperus rotundus*	Sub-tropical	1.86	3.97	1.85	7.69
Fragaria nubicola	Sub-trop	3.34	3	2.29	8.64	*Satyrium nepalense*	Sub-tropical	0.32	4.3	2.01	6.63
Aleuritopteris rufa	Sub-trop	2.96	2.09	2.09	7.14	*Capillipedium assimile*	Temperate	41.47	17.24	33.33	92.65
Erioscirpus comosus	Temperate	9.48	6.67	9.52	25.67	*Geranium nepalense*	Temperate	10.77	17.24	9.26	37.27
Drymaria diandra	Temperate	8.9	5.33	8.57	22.81	*Persicaria chinensis*	Temperate	5.39	13.79	7.41	26.59
Potentilla fulgens	Temperate	5.24	9.33	6.67	21.24	*Oxalis corniculata*	Temperate	11.85	6.9	3.7	22.45
Cynodon dactylon	Temperate	11.13	2.67	6.67	20.46	*Brachiaria villosa*	Temperate	12.03	3.45	3.7	19.18
Imperata cylindrica	Temperate	7.9	2.67	6.67	17.23	*Persicaria barbata*	Temperate	6.28	6.9	3.7	16.88
Selaginella subdiaphana	Temperate	8.61	1.33	5.71	15.66	*Globba racemos*	Temperate	2.33	6.9	3.7	12.93

Therophyte species	**Ecological region**	**RD**	**RF**	**RC**	**IVI**
Ageratum conyzoides	Tropical	29.68	5.97	6.37	42.02
Ageratina adenophora	Tropical	18.19	7.23	15.12	40.55
Euphorbia hirta	Tropical	2.72	4.72	5.31	12.74
Bidens pilosa	Tropical	4.16	2.20	3.18	9.54
Bidens bitternata	Tropical	4.76	1.57	2.65	8.99
Phyllanthus urinaria	Tropical	1.93	3.77	3.18	8.89
Dicliptera bupleuroides	Tropical	1.92	2.83	3.71	8.46
Ageratina adenophora	Sub-tropical	23.55	8.72	25.56	57.83
Ageratum conyzoides	Sub-tropical	24.94	7.56	10.33	42.83
Bidens bitternata	Sub-tropical	10.77	3.92	3.41	18.10
Bidens pilosa	Sub-tropical	4.94	3.78	2.77	11.49
Anaphalis busua	Sub-tropical	4.61	3.63	2.66	10.91
Swertia angustifolia	Sub-tropical	1.97	3.78	3.30	9.05
Cirsium verutum	Sub-tropical	1.27	4.36	3.19	8.82
Ageratina adenophora	Temperate	27.16	0.10	10.45	37.71
Ageratum conyzoides	Temperate	23.03	0.07	7.46	30.57
Anaphalis busua	Temperate	7.19	0.07	7.46	14.73
Swertia angustifolia	Temperate	3.51	0.09	8.96	12.56
Strobilanthes capitata	Temperate	4.20	0.07	7.46	11.74
Swertia paniculata	Temperate	4.06	0.07	7.46	11.60
Bidens bitternata	Temperate	8.06	0.03	2.99	11.07

Annex 5. The correlation coefficient values of environmental variables with species composition (analyzed by Adonis in r software) (Significannce: *p< 0.05**, *0.01*** and *0.001****)

S.N.	Explanatory variables	Df	Sum of square	R^2	F	Pr (>F)	Significance
1	Elevation	1	0.488	0.007	1.242	0.118	
5	Aspect	1	0.488	0.007	1.242	0.144	
6	RRI	1	0.324	0.005	0.823	0.788	
7	pH	1	0.633	0.009	1.616	0.012	*
8	N	1	1.873	0.027	4.865	0.001	***
9	P	1	0.821	0.012	2.099	0.001	***
10	K	1	0.908	0.013	2.326	0.001	***
13	Elev:pH	1	0.548	0.008	1.404	0.041	*
14	N	1	1.81	0.026	4.710	0.001	***
	Elev:N	1	0.463	0.007	1.205	0.2	
15	P	1	0.78	0.011	1.999	0.002	**
	Elev:P	1	0.457	0.007	1.172	0.196	
16	K	1	0.841	0.012	2.16	0.001	***
	Elev:K	1	0.551	0.008	1.414	0.038	*

Annex 6. The multicollinearity result between life form species and environment by Vif test

S.N.	**Life forms**	**Elev**	**RRI**	**pH**	**N**	**P**	**K**
1	Phanerophytes	3.34	1.13	1.25	2.52	1.31	1.91
2	Chamaephytes	2.99	1.11	1.24	2.34	1.21	1.74
3	Hemicryptophytes	3.34	1.13	1.25	2.52	1.31	1.91
4	Geophytes	3.05	1.10	1.21	2.37	1.24	1.75
5	Therophytes	3.32	1.13	1.25	2.51	1.31	1.90
6	Total life form	3.34	1.09	1.24	2.50	1.15	1.76

Annex 7. Detrended Correspondence Analysis results for plant life form species composition

Life forms	**Axis**	**Eigenvalues**	**Additive Eigenvalue**	**Decorana values**	**Axis lengths**
Phanerophytes	DCA1	0.58	0.58	0.59	4.84
	DCA2	0.36	0.36	0.39	4.46
Chamaephytes	DCA1	0.75	0.75	0.76	4.92
	DCA2	0.70	0.70	0.67	4.67
Hemicryptophytes	DCA1	0.55	0.55	0.56	4.77
	DCA2	0.48	0.48	0.49	4.62
Geophytes	DCA1	0.58	0.62	0.74	4.19
	DCA2	0.48	0.51	0.51	4.20
Therophytes	DCA1	0.46	0.46	0.72	4.16
	DCA2	0.48	0.48	0.51	3.81

Annex 8. The inertia result of life form species obtained by CCA ordination (A- Inertia and B Proportion)

	Phanerophytes		**Chamaephytes**		**Hemicryptophytes**		**Geophytes**		**Therophytes**	
	Inertia	**Proportion**	**Inertia**	**Proportion**	**Inertia**	**Proportion**	**Inertia**	**Proportion**	**Inertia**	**Proportion**
Total	13.83	1	13.53	1.00	16.51	1	10.98	1	11.56	1
Constrained	0.93	0.07	0.76	0.06	0.79	0.05	0.46	0.04	0.59	0.05
Unconstrained	12.91	0.93	12.77	0.94	15.58	0.95	10.52	0.96	10.97	0.95

Annex 9. The accumulated constrained eigenvalues of life forms with explanatory variables in CCA analysis.

Life forms	**Axis**	**Eigenvalue**	**Proportion Explained**	**Cumulative Proportion**
Phanerophytes	CCA1	0.46	0.51	0.50
	CCA2	0.12	0.12	0.62
Chamaephytes	CCA1	0.23	0.30	0.30
	CCA2	0.15	0.20	0.49
Hemicryptophytes	CCA1	0.28	0.36	0.36
	CCA2	0.14	0.17	0.54
Geophytes	CCA1	0.23	0.49	0.49
	CCA2	0.09	0.19	0.68
Therophytes	CCA1	0.20	0.33	0.33
	CCA2	0.10	0.17	0.51

Annex 10. Results of centroids for factor constraints (north and south aspects)

Life forms	**Axis**	**Aspect N**	**Aspect S**
Phanerophytes	CCA1	0.08	-0.10
	CCA2	-0.22	0.27
Chamaephytes	CCA1	-0.34	**0.51***
	CCA2	0.04	-0.06
Hemicryptophytes	CCA1	0.22	-0.23
	CCA2	-0.48	0.49
Geophytes	CCA1	-0.04	0.07
	CCA2	**-0.58***	**1.04***
Therophytes	CCA1	-0.19	0.20
	CCA2	**-0.83***	**0.87***

(Significance: $P < 0.05$)

Annex 11. List of high species score bearing species of life forms

Phanerophyte species	**Species score**		**Chamaephyte species**	**Species scores**		**Hemicryptophyte species**	**Species scores**	
	CCA1	**CCA2**		**CCA1**	**CCA2**		**CCA1**	**CCA2**
Acacia catechu	1.71	0.86	*Abelmoschus manihot*	0.22	0.75	*Adiantum incisum*	-0.01	0.61
Alstonia scholaris	1.83	0	*Amaranthus viridis*	-0.43	0.59	*Aleuritopteris doniana*	-0.43	0.8
Buchanania cochinchinensis	1.53	0.75	*Artemisia indica*	-0.27	0.36	*Anemone rivularis*	1.14	-0.34
Calopogonium mucunoides	1.35	0.64	*Asparagus racemosus*	0.2	0.65	*Bistorta ampexicaulis*	1.26	-0.14
Careya arborea	2.01	1.79	*Clinopodium umbrosum*	0.72	0.09	*Chromolaena odorata*	-0.94	0.63
Cassia fistula	1.35	1.05	*Desmodium laxiflorum*	1.18	0.23	*Cymbopogon jwarancusa*	1.09	-0.12
Clerodendrum infortunatum	1.7	1.11	*Dipsacus inermis*	0.36	-0.43	*Dryopteris cochleata*	0.44	0.94
Coccinia grandis	1.74	1.14	*Girardinia diversifolia*	0.8	-0.61	*Echinochloa colona*	-0.44	1.02
Combretum roxburghii	1.58	1.48	*Isodon coesta*	0.55	-0.3	*Eleusine incana*	-0.29	1.37
Dalbergia latifolia	2.3	1.53	*Ocimum gratissimum*	0.26	0.27	*Equisetum arvense*	0.52	0.69
Dalbergia sissoo	2.04	1.32	*Ophiorrhiza fasciculata*	0.36	-0.12	*Evolvulus nummularius*	-1.35	1.28
Desmodium gangeticum)	1.39	0.91	*Pilea scripta*	0.48	-0.1	*Lepisorus bicolor*	1.4	-0.44
Dumasia villosa	1.41	0.43	*Roylea cinerea*	1.46	0.6	*Lepisorus nudus*	1.05	0.42
Eucalyptus camaldulensis	2.17	1.73	*Rumex hastatus*	0.05	0.41	*Melanoseris microrhiza*	1.37	-0.77
Ficus religiosa	1.22	1.14	*Sida cordata*	-0.3	0.43	*Panisea demissa*	1.67	-0.93
Justicia gendurosa	0.99	1.02	*Strobilanthes hamiltoniana*	0.92	-0.62	*Paspalum scrobiculatum*	1.3	-0.98
Kydia calycina	0.39	1.14	*Strobilanthes wallichii*	0.31	0.25	*Peperomia tetraphylla*	1.46	0.87
Leucaena leucocephala	1.06	1.29	*Thespasia lampas*	-0.64	0.3	*Onychium lucidum*	0.98	-0.09
Milletia extensa	1.8	2.61	*Triumfetta annua*	0.22	-0.04	*Potentilla fulgens*	1.45	-0.11

Geophyte species	Species scores		Therophyte species	Species score	
	CCA1	**CCA2**		**CCA1**	**CCA2**
Arundina graminifolia	1.48	-0.15	*Adenostemma lavenia*	0.62	-0.22
Bambusa balcooa	-0.59	0.6	*Canscora diffusa*	0.82	-1.01
Begonia picta	-0.33	0.54	*Chenopodium album*	1.21	0.59
Campanula pallida	0.88	-1.37	*Conyza canadensis (Syn. Erigeron canadensis*)	0.33	0.6
Carex filicina	0.35	1	*Cyanthillium cinereum*	-0.01	0.53
Colocasia fallax	0.31	0.82	*Dicliptera bupleuroides*	-0.47	0.64
Cyperus distans	-0.83	0.59	*Emilia sonchifolia*	-0.63	0.79
Drepanostachyum intermedium	-0.2	0.96	*Fagopyrum acutatum*	0.53	-0.84
Geranium nepalense	1.24	-0.21	*Gentiana pedicellata*	0.62	-0.36
Globba clerkei	0.78	-0.86	*Impatiens scabrida*	0.84	-0.6
Habenaria dentata	0.04	1.37	*Impatiens sulcata*	0.85	-1.1
Himalayacalamus fimbriatus	-0.35	0.54	*Lactuca dissecta*	-0.73	0.76
Oxalis latifolia	0.62	-0.25	*Leucas cephalotes*	-0.38	0.54
Persicaria capitata	1.15	0.07	*Micromeria biflora*	0.8	-0.76
Persicaria chinensis	1.03	-0.26	*Pedicularis bifida*	0.68	0.5
Plantago major	0.61	0.03	*Strobilanthes capitata*	0.69	-0.48
Polygonatum punctatum	0.88	0.06	*Swertia angustifolia*	0.61	-0.33
Remusatia vivipara	0.85	-0.29	*Swertia nervosa*	0.62	-0.5
Rhaphidophora glauca	-0.76	1.2	*Swertia paniculata*	0.76	-0.26
Scutellaria scandens	0.34	0.63	*Vicia hirsuta*	-0.08	1.02

Annex 12: List of lichen species of Arghakhanchi district and surrounding region

Lichen species	Abbreviation	Family	Thallus form	Habitat	Species score	
					CCA1	**CCA2**
Bacidia personata Malme 1935	Bac_per	Ramalinaceae	Cru	Corticolous	-1.99	-1.28
Bulbothrix isidiza (Nyl.) Hale 1974	Bul_isi	Parmeliaceae	Fol	Corticolous	0.70	-0.40
Cetraria islandica (L.) Ach. 1803	Cet_isl	Parmeliaceae	Fru	Terricolous	-0.49	0.60
Cladonia amaurocraea (Flörke) Schaer 1887	Cla_ama	Cladoniaceae	Fru	Terri. & Ligni	-0.22	1.03
Cladonia coniocraea (Flörke) Spreng. 1827	Cla_con	Cladoniaceae	Fol	Terri. & Ligni	1.03	-0.63
Cladonia fimbriata (L.) Fr. 1831	Cla_fim	Cladoniaceae	Fru	Terricolous	-0.34	0.85
Cladonia ramulosa (With.) J.R. Laundon 1984	Cla_ram	Cladoniaceae	Fru	Terri. & Ligni	0.60	-0.10
Cladonia verticillata subsp. *verticillata* (Hoffm.) Ahti 1980	Cla_ver	Cladoniaceae	Fru	Terricolous	0.60	-0.10
Coccocarpia erythroxyli (Spreng.) Swinscow & Krog 1976	Coc_ery	Coccocarpiaceae	Fol	Corti & Teri	0.50	-0.02
Everniastrum cirrhatum (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch 2013	Eve_cir	Parmeliaceae	Fol	Corticolous	-0.49	0.60
Everniastrum nepalense (Taylor) Divakar, A. Crespo, Sipman, Elix & Lumbsch 2013	Eve_nep	Parmeliaceae	Fol	Corticolous	-0.34	0.97
Heterodermia comosa (Eschw.) Follmann & Redón 1972	Het_com	Physciaceae	Fol	Corticolous	-0.62	-0.64

Heterodermia diademata (Taylor) D.D. Awasthi 1973	Het_dia	Physciaceae	Fol	Corticolous	0.93	-0.72
Heterodermia incana D.D.Awasthi 1973	Het_inc	Physciaceae	Fol	Corticolous	0.60	-0.10
Heterodermia leucomela (L) Poelt 1965	Het_leu	Physciaceae	Fol	Corti & Ligni	-0.99	0.23
Heterodermia obscurata (Nyl.) Trevis. 1869	Het_obs	Physciaceae	Fol	Corticolous	-0.46	0.89
Heterodermia speciosa (Wulfen) Trevis. 1868	Het_spe	Physciaceae	Fol	Corti & Ligni	0.80	-0.48
Hypotrachyna cirrhata (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch 2013	Hyp_cir	Parmeliaceae	Fol	Corticolous	0.23	0.12
Hypotrachyna nepalensis (Taylor) Divakar, A. Crespo, Sipman, Elix & Lumbsch 2013	Hyp_nep	Parmeliaceae	Fol	Corticolous	0.93	-0.72
Hypotrachyna orientalis (Hale) Hale 1974	Hyp_ori	Parmeliaceae.	Fol	Corti & Teri	-1.60	-0.65
Lecidia sp	Lec_sp	Lecideaceae	Cru	Saxicolous	-0.46	0.89
Lepraria lobificans Nyl. 1873	Lep_lob	Sterocaulaceae	Cru	Corti & Teri	-0.92	0.61
Leptogium delavayi Hue 1925	Lep_del	Collemataceae	Fol	Corticolous	0.82	-0.73
Leptogium sp	Lep_sp	Collemataceae	Fol	Corticolous	-0.34	0.85
Parmelia cirrhata (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch 2013	Par_cir	Parmeliaceae	Fol	Corticolous	0.25	-0.03
Parmelia squarrosa Hale 1971	Par_squ	Parmeliaceae	Fol	Corticolous	1.40	-0.32
Parmelia sulcata Taylor 1836	Par_sul	Parmeliaceae	Fol	Corti & Ligni	0.17	-0.01
Parmelinella simplicior (Hale) Elix & Hale, 1987	Par_sim	Parmeliaceae	Fol	Corticolous	-0.17	-0.32
Parmelinella wallichiana (Taylor) Elix & Hale 1987	Par_wal	Parmeliaceae	Fol	Corti & Saxi	-0.81	0.67
Parmotrema arnoldii (Du Rietz) Hale 1974	Par_arn	Parmeliaceae	Fol	Corticolous	-0.34	1.19

Parmotrema pseudonilgherrense (Asahina) Hale 1977	Par_pse	Parmeliaceae	Fol	Corticolous	1.23	-0.33
Parmotrema reticulatum (Taylor) M. Choisy 1952	Par_ret	Parmeliaceae	Fol	Corti & Ligni	-1.95	-1.23
Parmotrema sancti-angelii (Lynge) Hale 1974	Par_san	Parmeliaceae	Fol	Corticolous	-0.46	0.89
Parmotrema stuppeum (Taylor) Hale1974	Par_stu	Parmeliaceae	Fol	Corticolous	0.25	-0.03
Parmotrema thomsonii (Stirt.) A. Crespo, Divakar & Elix 2010	Par_tho	Parmeliaceae	Fol	Corticolous	0.60	-0.10
Parmotrema tinctorum (Despr. ex Nyl.) Hale 1974	Par_tin	Parmeliaceae	Fol	Corti & Ligni	0.60	-0.10
Pyxine berteriana (Fée) Imshaug 1957	Pyx_ber	Caliciaceae	Fol	Corti & Teri	-0.14	0.24
Pyxyne spp	Pyx_spp	Caliciaceae	Fol	Corticolous	0.17	0.20
Ramalina calicaris (L.) Fr. 1813	Ram_cal	Ramalinaceae	Fru	Corticolous	0.30	0.07
Ramalina capitata (Ach.) Nyl. 1872	Ram_cap	Ramalinaceae	Fru	Corticolous	-0.73	0.62
Ramalina conduplicans Vain.	Ram_con	Ramalinaceae	Fru	Corticolous	-0.46	0.89
Ramalina usnea (L.) R. Howe 1914	Ram_usn	Ramalinaceae	Fru	Corticolous	-0.22	1.03
Usnea aciculifera Vain. 1921	Usn_aci	Parmeliaceae	Cru	Saxi & Terri	0.17	-0.01
Usnea baileyi (Stirt.) Zahlbr. 1909	Usn_bai	Parmeliaceae	Fru	Corticolous	0.70	-0.33
Usnea cornuta Körb.1859	Usn_cor	Parmeliaceae	Fru	Corticolous	-0.57	0.96
Usnea orientalis Motyka 1937	Usn_ori	Parmeliaceae	Fru	Corticolous	0.17	0.20

FIELD PHOTOS

1. Diploknena butyracea (Chiuri) forest. 2. *Beaumontia grandiflora*. 3. *Chlorophytum nepalense.* 4. Habenaria dentata 5. *Piper peepuloides* and 6. *Spatholobus parviflorus*

7. Downward scene from Masina tower, 8. & 9. Area covered by *Ageratina adenophora*, Arichour, Sengleng, 1610 m. 10. *Oberonia ensiformis*, 11. Upward scene of Jalkanda from Diverna & 12. Three species of Pine (*Pinus roxburghii*, *P. wallichiana* & *P. patula* at Jalkanda, 1920 m.

Publications

1. Nepali, B.R., Skartveit, J., & Baniya, C. B. (2022). Impacts of slope aspects on altitudinal species richness and species composition of Narapani-Masina landscape, Arghakhanchi, West Nepal. *Journal of Asia-Pacific Biodiversity*, https://doi.org/10.1016/j.japb.2021.04.005

2. Nepali, B.R., Skartveit, J., & Baniya, C. B. (2020). Interpolated Altitudinal Species Richness in Arghakhachi district of Nepal. *Journal of Institute of Science and Technology,* **25**(1): 52-60. doi: https://doi.org/10.3126/jist.v25i1.29447

3. Nepali, B.R., Skartveit, J. & Baniya, C.B. (2020). Altitudinal Pattern of Pteridophytes in Arghakhanchi district, West Nepal. *Journal of Plant Resources*, 18 (1), 173-182.

4. Nepali, B. R., Skartveit, J. & Baniya, C.B. (2022). Diversity Patterns of Vascular Plants at Varied Elevations in Arghakhanchi, West Nepal. *Journal of Plant Resources* Special Issue 20(2), 29-39. https://doi.org/10.3126/bdpr.v20i2.56955

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Original Article

Impacts of slope aspects on altitudinal species richness and species composition of Narapani-Masina landscape, Arghakhanchi, West Nepal

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A B S T R A C T

This study aimed to find out the roles of altitude, slope aspect, and soil factors in species richness in the Narapani-Masina landscape, Arghakhanchi, Nepal. We surveyed forest plant communities by sampling 192 statistically representative 10 × 10 m sample plots from 64 sites representing all 100 elevation bands of 4 slope aspects (East, South, West, and North) of the landscape. We considered the species present in all plots of each 100 m contour elevation of four aspects as species richness of that elevation band. We collected the soil sample from 10 × 10 × 10 cm plot of 10 cm below the ground level at four corners of plant sampled plots to estimate the soil nutrients in a laboratory. We estimated the correlation, regression, Tukey post hoc test, PerMANOVA, and canonical correspondence analysis to show the relationship between environment and response variables. We found a significant negative relationship between species richness and altitude and soil nitrogen. The species richness showed a unimodal structure with elevation. The slope aspect showed a significant effect on species composition, but not on species richness. This study concludes that the increasing trend of soil N, P, and K with altitude showed a negative relation with species richness.

Introduction

Global patterns of species ranges and richness are the product of many interacting factors such as environmental conditions, competition, geographical area, and historical/evolutionary development (Criddle et al 2003). Elevation and latitude are well-known broad-scale factors affecting species richness (Hakwins et al 2003). The climatic factors (temperature, potential evapotranspiration, length of the growing season, humidity, air pressure, ultraviolet radiation, moisture index, and rainfall) vary with elevation (Funnell and Parish 2001; Chang-Ming et al 2005) and exert a strong controlling influence on the distribution in all biomes (Miao and Jianmeng 2015).

Rahbek (1995, 1997) showed the three types of response of species richness to altitude (monotonic decline, hump-shaped, and monotonic incline). Globally, more than half of the studies on elevational diversity pattern show unimodal responses (Hakwins et al 2003), which may be explained by altitude (Zhou et al 2019), area (Lomolino 2000; Lee et al 2013), mid domain effect (Sanders 2002; McCain 2004), mountain-mass effect (Flenley 1994), rainfall (Rosenzweig 1992), resource diversity (Gentry 1988; Hrivnak et al 2014), productivity (Sanders et al 2007), temperature (Pounds et al 2006; Vinka et al 2010), competition (Bryant et al 2008), and environmental heterogeneity (Gerstner and Kreft 2014). In the Himalayas, with high altitudinal gradients and extreme slopes, climatic zones may change rapidly and this is reflected by noticeable changes in the community structures even at a small distance (Chawla et al 2008; Sinha et al 2018). Patterns of altitudinal species richness are indicative of broad-scale diversity mechanisms, which are affected by water and temperature (Chang-Ming et al 2005; Grytnes and McCain; 2007). Altitude and aspect have effects on β-diversity (Gallardo-Cruz et al 2009) or may function as limiting factors on plant species or ecosystem properties and processes in the mountains (Xiang et al 2017).

The observed elevational trends for species vary among groups of organisms and from one area to another. Regional and local patterns in plant species richness differ concerning resource

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availability (Cornwell and Grubb 2003). Nutrient availability plays a variable role in germination or seedling establishment and species dominance according to species composition along an altitudinal gradient (Wenk and Dawson 2007). High water availability usually leads to higher species richness, but higher nutrient availability usually leads to lower species richness (Palpurina et al 2016). There is an inverse correlation between nutrient resorption efficiency of plants and soil nutrients content (Zhiqiang et al 2018). On the other hand, forests are generally species-rich in high nutrient sites (Peet and Christensen 1988). All plants and animals require nitrogen to make proteins in their body. Phosphorus is needed to make phosphate compounds, and potassium plays an activation role in photosynthesis, CO_2 uptake, and the opening and closing of stomata. Available soil nitrogen is the most limiting factor for plant growth and plays a role in increasing the diversity of plants (Fisher et al 2013). Soil pH shows influences on biogeochemical processes like trace element mobility, nitrification, and denitrification (Neina 2019) and it indicates soil condition and the expected direction of many soil processes. Most of the plant nutrients are more available at slightly acidic to slightly alkaline soil – pH 6.5 to 7.5 (Khadka et al 2016). Other environmental factors precipitation (Palpurina et al 2016), temperature, energy flow (Rosenzweig 1995), latitude, altitude, and depth gradients (Rohde 1992) have a co-operating role with respect to the effect of nutrients on species diversity. The interaction between water and energy provides a good explanation (over 60%) for globally extensive plant and animal diversity gradients (Hawkins et al 2003).

The presence of species in a small area depends mainly on a suitable local niche but the distribution of species over large geographical areas depends on climatic conditions (Rahbek 2005). Local diversity bears a noticeable dependence upon regional diversity (Ricklefs 1987). Minor changes in microclimatic environmental variables such as slope, aspect, and soil nutrients with altitude may create unusual modifications of the local diversity. The temperature shows negative correlation with species of large distribution range but positive relation with species of small distribution range (Pan et al 2016). The contribution of many smaller landscapes or mountains to biodiversity conservation is not well known. The small areas also may help to add to global biodiversity conservation through matrix habitat improvement, connectivity, and preservation of localized ecosystems (Baldwin and Fouch 2018). The numerous studies based on altitudinal gradients have not focused on slope aspects. In the study of Maren et al (2015), the aspect (north and south) was found to be a main ecological driver in altitudinal species richness. There are fewer studies about species richness with relation to slope aspects in Nepalese Himalayas. This study is based on the hypothesis that the slope aspect brings significant differences in altitudinal species richness patterns.

The specific objectives of this study are:

(1) quantify vascular plant species diversity
(2) discuss the role of altitude, slope aspect, and soil factors in species richness and species composition.

Material and methods

Study area

The study site: Narapani-Masina landscape (approximately 27°45′–27°57 N and 82°45′–83°18′E), is centered in the south part in Arghakhanchi district, west Nepal and extending between about 210 and 2200 m asl (personnel field visit). This landscape extends from the east border (Palpa district) to Jhimruk and Rapti rivers (west border) and extends for approximately 62 km east-west and 39 km north-south. The north face of this hill (aerial distance 4.8 km) is steeper than the south face (aerial distance about 17.5 km). This hill lies at Mahabharat range and occupies the total area of Sitganga municipality and Panena rural municipality and 2 wards of each Sandhikharka and Bhumikasthan municipalities of Arghakhanchi district (Figure 1).

According to the climatic records of station: Khanchikot, which is located on this area, average annual temperature and annual rainfall of the area are 14.9°C and 1627.7 mm (DHM, 2017), respectively. The south part of this hill is hot and warm and dominated with *Shorea-Syzygium* forest. The east and north faces are moist and covered by *Shorea* forest, *Schima-Castanopsis* forest, and *Pinus* forest, while the west face is covered by *Shorea-Diploknema* forest, *Pinus* forest, and *Quercus-Xylosma* forest (personnel observation). Most of the forest of Arghakhanchi district lies in the southern part of this hill. The region of the hill above than 1200 m is steeper and moist. Narapani (tourist area and former headquarter of Arghakhanchi district) and a famous Hindu temple – Supa Deuali are located at 1700 and 1380 m respectively of this landscape.

Sampling design and plant collection

The overall altitudinal range of the Narapani-Masina landscape (200–2200) was divided into 20, 100 m wide elevation bands. The field was visited and sampled by a plot of 10 × 10 m at each 100 m elevation band in October–November 2018. Based on the availability of different forest types, the number of sample plot laid varied from 2 to 3 in each elevation band. The distance between the two sample plots varied from 100 to 150 m (Figure 2).

Voucher specimens were collected, properly dried, and kept in herbarium sheets. In addition to GPS data, other micro-ecological characters were also recorded for each herbarium specimen. All herbarium specimens were identified with the help of relevant taxonomic literature (Gurung 1984; Polunin and Stainton 1984; Rajbhandari and Baral 2010; Rajbhandari et al 2011, 2012, 2015; Fraser-Jenkins et al 2015; Rajbhandary et al 2017; Fraser-Jenkins and Kandel 2019). Some species were also identified with the help of consulting experts and compared to specimens deposited at KATH and TUCH. All these identified herbarium specimens were submitted in the TUCH.

Each plot was divided into four subplots and the presence/absence of all rooted species of vascular plants (Pteridophytes,

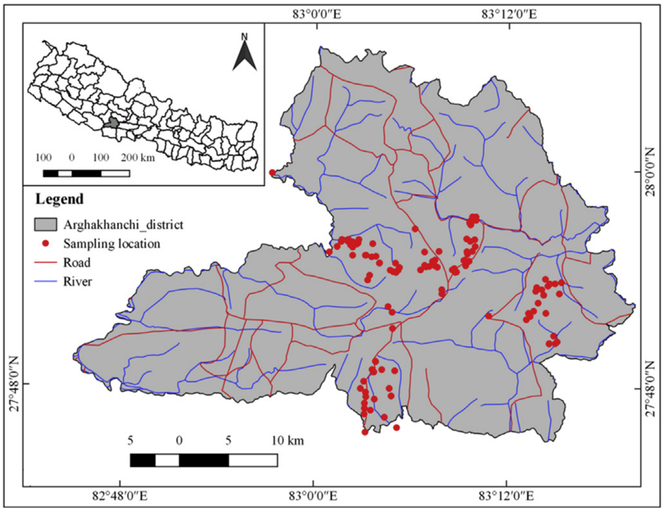

Figure 1. Map of Arghakhanchi district with sampling spots.

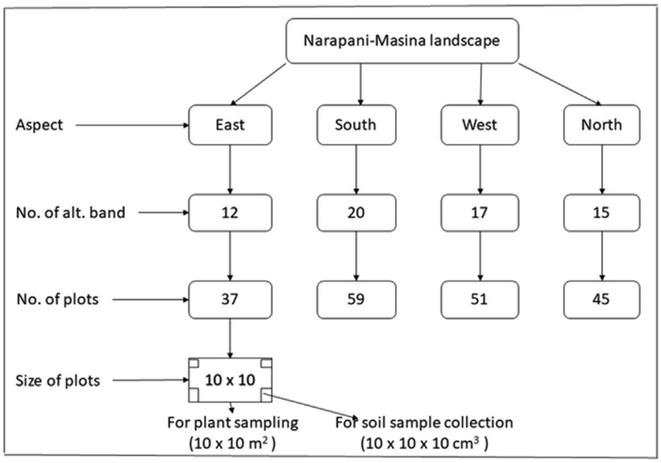

Figure 2. Outline of sampling design for primary data collection.

gymnosperms, and angiosperms) was enumerated. The presence of a species among four subplots within a plot was finally recorded as 1. All species that occurred inside the sampled plots were identified with the help of field guides such as Mager and Burrow (2007). At least one sample of each plant specimen was collected as a voucher specimen in order to verify the identification

Environmental variables

Environmental factors (relative radiation index, altitude, aspect, soil pH, nitrogen, phosphorus, and potassium) are considered as explanatory variables in this study. The coordinates (longitude and latitude), aspect, and altitude of each plot location were also measured using GPS (*eTrex*). Similarly, the slope of the sampled plots was measured using a clinometer.

Soil composition effects on the distribution of plants because they are dependent on the soil to survive. About 1 kg soil sample was collected from 15 cm below the surface at 4 corners of each sampling plot.

The soil nutrients (pH, nitrogen, phosphorus, and potassium) were estimated following the chemical analysis method by Jones (1991) in Soil, Water, and Air Testing Laboratories (SWAT), Kathmandu, Nepal.

Statistical analysis

The relative radiation index (RRI) can be used as a measure for comparison of the distribution of direct solar radiation throughout a specific studied area (Mammassis et al 2012).

The RRI was calculated by using the formula given by Ôke (1987).

$$\mathrm{RRI} = \mathrm{Cos}(180^\circ - \Omega).\ \mathrm{Sin}\beta.\ \mathrm{Sin}\ \Phi + \mathrm{Cos}\beta.\ \mathrm{Cos}\ \Phi$$

where Ω is an aspect, β is the slope, and Φ is the latitude of each plot. It gives a relative value of how much solar radiation a particular spot receives at noon at the equinoxes. Its value ranges from +1 to −1.

The total species of all sampled plots of each 100 m elevational band was considered as species richness of that spot. The diversity indices (Shannon Wiener diversity and Simpson diversity) were estimated by using "diversity" function through the *vegan* package (Oksanen et al 2019).

Species diversity is the aggregate form of species richness and evenness. Hurlbert (1971). The evenness was calculated by using the Shannon–Weiner index and species richness according to formula proposed by Hurlbert (1971).

$$E = \frac{H}{\log(S)}$$

where, E = Evenness of species, H = Shannon-Wiener Index and S = Species richness

The slope aspect is a qualitative environmental variable. So, dummy data of aspects (denoting by 1 for a particular aspect and 0 for others in the column of each aspect) were applied for correlation purposes. The correlation of species richness with environmental variables was determined through Pearson correlation (Kassambara 2018). We applied a generalized linear model (GLM) to express the relations of environmental variables with species richness of different aspects and in total (Hastie and Pregibon 1993). The quasi-Poisson family of error distributions was applied to remove over dispersion.

Similarly, the effect of 4 aspects (east, west, north, and south) on species richness was tested by ANOVA using Tukey post hoc test (Kassambara 2019). The effect of aspects on species richness was confirmed by the application of a generalized linear mixed model (*GLMM*) (Berridge and Crouchley 2011) in R version 4.0.2.

We tested the relationships of altitude and aspects with vegetation community composition by permutational multivariate analysis of variance (PerMANOVA) by function Adonis (Anderson 2001) on the Bray-Curtis distance matrix.

We started the ordination to show the environment species relation by applying DCA in R vegan. The length of the gradient of the DCA axis I for total data set was more than 2.5 standard deviation units, suggested that (according to Leps and Smilauer 2003) unimodal ordination methods (e.g. canonical correspondence analysis [CCA]) were preferable.

We tested the usefulness of CCA through the variance inflation factor before CCA. CCA is used to analyze species environmental composition. CCA is a direct gradient analysis that displays the variation of vegetation concerning the included environmental factors by using environmental data to order samples (Kent 2011). We included only the species of high species score to make the CCA plot. The species score (stand score) represent the centroid of the species or the mode of the unimodal species response curve. All these analyses were done in R (R Core Team 2020).

Results

Vascular plant species diversity

We found a total of 460 vascular plant species representing 112 families and 331 genera in the Narapani-Masina landscape. There was great variation in species richness as well as life form richness between the four aspects of the study area. South and north aspect had the highest (369) and the lowest (316) species richness, respectively (Table 1). As for diversity indices, the average Shannon-Wiener index and Simpson index values ranged between 3.78–3.88 and 0.97–0.98, respectively. The value of both diversity indices is higher in east and west aspects.

The correlation between explanatory and response variables

Pearson correlation analysis was used to show the correlation between environmental variables and species richness (Table 2). There were significant positive relations of altitude with soil nitrogen (r = 0.61), phosphorus (r = 0.26), and potassium (r = 0.4). On the other hand, species richness showed a significant negative correlation with soil nitrogen (r = −0.29) and altitude (r = −0.31).

Table 1. Species richness of different aspects of different plant life forms.

S.N.	Aspects	Species richness						Shannon-Wiener index (H')	Evenness (E)	Simpson index (D)	Altitudinal range (m)
		Herbs	Climbers	Ferns	Shrubs	Trees	Total				
1	East	155	21	28	67	76	347	3.86 ± 0.35	1.52	0.98 ± 0.01	700–1850
2	South	168	20	31	71	79	369	3.78 ± 0.46	1.47	0.97 ± 0.02	200–2200
3	West	153	20	27	74	74	348	3.88 ± 0.55	1.53	0.98 ± 0.02	500–2000
4	North	152	15	23	65	61	316	3.78 ± 0.42	1.50	0.97 ± 0.01	800–2200
Grand total		207	26	40	93	94	460				

In the case of aspects, soil pH showed significant negative relations with the east and west sides. RRI showed a statistically positive correlation in the west but negative in the south aspects. Similarly, nutrients N, P, K also showed positive in one aspect and negative in other aspects (Table 2).

Relation between environmental variables and species richness

The relations of all environmental variables except aspect on species richness were regressed using GLM. Species richness increased with altitude at first upto more or less mid altitudinal range, then richness started to decrease with increasing altitude. This gives a unimodal structure in total and all aspects even though the R^2 values vary (Figure 3 and Appendix 1). This model had best fit in the north aspect ($R^2 = 0.64$ & $p < 0.05$).

Other explanatory variables RRI, soil pH, nitrogen (N), phosphorus (P), and potassium (K) showed linear relationships with altitudinal species richness, except the unimodal structure of phosphorus in the north aspect ($R^2 = 0.58$) and total species (Appendix 1). Soil pH, N, and P showed stronger correlations with species richness in north than other aspects.

The regression analysis of altitude on environmental factors (pH, N, P, and K) showed variable and insignificant effects.

The slope aspect is the qualitative variable. The Tukey post hoc test showed that the aspects showed no significant effect on species richness and altitudinal nitrogen content (Figure 4). But, the effect of aspects on RRI, pH, P and K distribution was statistically significant ($p < 0.05$).

The relation of species distance matrix with environmental variables

The environmental factors showed different effects on species richness and vegetation community composition. The distance-based tests of multivariate dispersions of species of the community showed that altitude ($R^2 = 0.073$ & $P = 0.001$) and aspects ($R^2 = 0.046$ & $p = 0.003$) had significant relations (Table 3) with species composition. Similarly, the soil P ($R^2 = 0.014$ & $p = 0.046$) and K ($R^2 = 0.026$ & $p = 0.001$) also showed significant relationships with species composition.

Table 2. Correlations among species richness and environmental variables.

Variables	Species richness	altitude	RRI	pH	N	P	K
Species richness	1						
altitude	−0.31**	1					
RRI	−0.15	0.17	1				
pH	−0.05	−0.21	−0.06	1			
N	−0.29**	0.61***	−0.01	−0.05	1		
P	−0.12	0.26*	−0.09	−0.19	0.22*	1	
K	−0.09	0.4***	0.19	−0.4	0.02	0.33**	1
South	−0.05	−0.13	−0.46***	0.34**	0.2	−0.13	−0.58***
East	0	−0.03	0.04	−0.32**	0.09	−0.23*	0.27**
North	−0.08	0.09	0.2	0.18	−0.1	0.16	0.28**
West	0.14	0.08	0.26*	−0.23*	−0.21*	0.21*	0.1

Statistically significant (p value): *** < 0.001, ** < 0.01, * < 0.05.

Species environment composition

The relation between species composition and environmental variables analyzed by ordination methods DCA and CCA showed that every species has different relationships with explanatory variables. The DCA result of species richness showed the axis length of DCA1was 3.23 and a decreasing trend of axis length towards DCA2 and DCA3 (Table 4). It indicated that the CCA ordination method is suitable to show the relation of species-environment composition (Leps and Smilauer 2003).

The test of goodness of CCA through the variance inflation factor showed that there was no multicollinearity among the environmental variables (Tables 5 and 6).

The CCA analysis showed that the constrained variables consisted 18 % (Inertia value 1.476) out of the total inertia value (8.284). It showed that constraints (environmental variables) explain only 18% of the causes of the vegetation distribution. There was a significant relationship between species richness and environment variables in CCA ($p < 0.05$). The first two axes of CCA explained 27 and 14 % (total 41 %) variation in species richness. The eigenvalues of these axes 1 and 2 accounted for 0.32 and 0.16, respectively (Table 5).

The altitude (canonical correlation $r = 0.99$), nitrogen, (canonical $r = 0.51$), and phosphorus (canonical $r = 0.24$) variables were most correlated with CCA axis 1. Similarly, other variables: pH (canonical $r = -0.30$), potassium (canonical $r = 0.56$), RRI

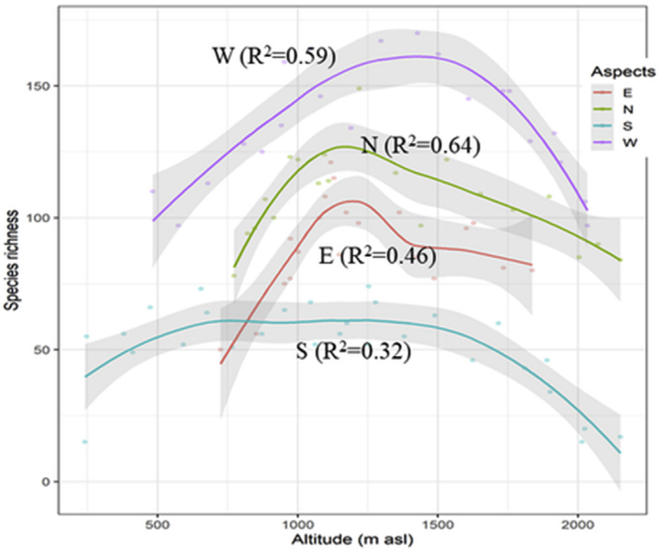

Figure 3. Plant species distribution against altitude in 4 aspects (E-East, N-North, S-South, and W-west).

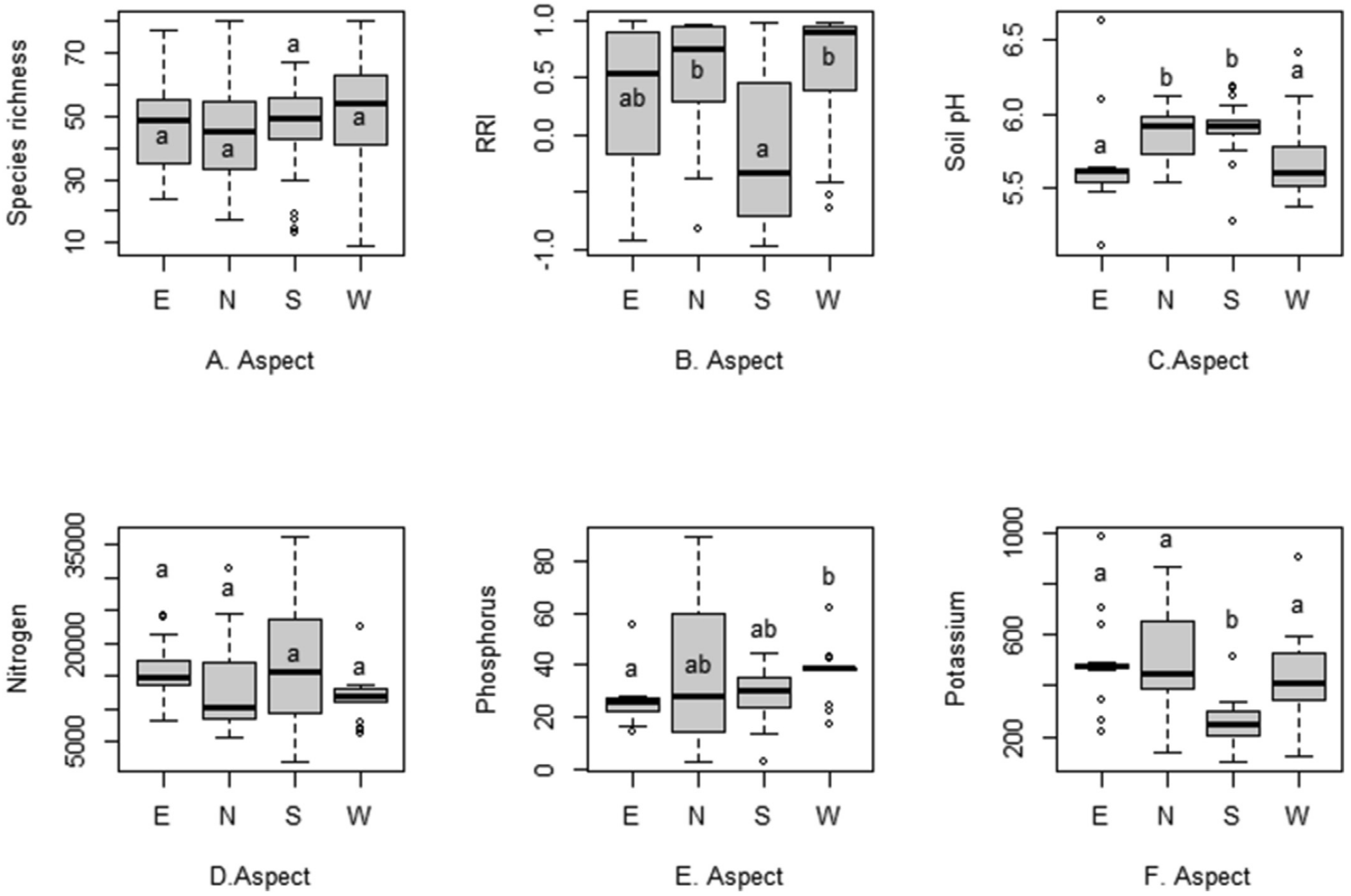

Figure 4. The post hoc analysis with Tukey's test.

(canonical r = 0.39) and south, west and north aspects were most correlated with axis 2 of CCA (Table 6).

The CCA ordination shows the distribution of the species based on their weighted average of the present in 192 sampling sites. According to the weighted average of species present in each of the sites, their direct relation to environmental variables is determined for each site. The soil nitrogen and phosphorus showed a positive relation with altitude. Similarly, the soil pH showed a positive response mainly in the south aspect and negative with K and RRI as well as west and north aspects. South aspects showed a strong effect as altitude in species distribution.

The species score represents the centroid of the species, or the mode of the unimodal species response curve (Ter Braak 1986). The species *Zanthoxylum armatum* (CCA species score: 0.85), *Macaranga denticulata* (0.90), *Melastoma malabathricum* (0.27), *Asparagus racemosus* (0.20), *Saccharum spontaneous (*0.14), *Pyrus pashia* (0.23) showed high frequency at high nitrogen-containing sites. Similarly, dominancy of the species *Fragaria nubicola* (0.51), *Centella asiatica* (0.18), *Reinwardtia indica* (0.20), *Bauhinia purpurea* (0.02), *Semecarpus anacardium* (0.19) on sites of a high content of phosphorus indicated that they were phosphorus loving species. The species *Albizia lebbeck* (0.79), *Berberis aristata* (1.74), *Berberis asiatica* (0.98), *Dendrobium longicornu* (1.25), *Drynaria propinqua* (0.91), *Prunus cerasoides* (0.99), *Selinum wallichianum* (1.23), *Quercus semicarpifolia* (1.44), *Geranium nepalense* (1.08), *Oleandra wallichii* (0.81), *Myrica indica* (0.72) showed positive relation with altitude because they were present at high altitude (Figure 5A and B).

The species *Barlaria cristata* (0.04), *Imperata cylindrica* (0.02), *Xylosma longifolium* (0.19), *Digitaria ciliaris* (-0.11) show the maximum abundance towards the direction of the highest content of potassium. The species scores indicated that these were potassium loving species. Similarly, *Inula cappa* (-0.07), *Euphorbia hirta* (-0.11), *Brachiaria villosa* (-0.10), *Gnaphalium affine* (-0.16), etc. were dominantly present at sites of high RRI value. Some species showed strong negative relation with nitrogen, phosphorus, and potassium but exposed a positive relationship with pH. *Evolvulus nummularia* (-0.08), *Setaria parviflora* (-0.21), *Ageratum conyzoides* (-0.04), *Achyranthes aspera* (-0.20), *Cynoglossum zeylanicum* (-0.41), *Terminalia tomentosa* (-0.43), *Desmodium elengans* (-0.24), *Indigofera atropurpurea* (-0.25) were more abundant in the high pH containing sites mainly in south aspect. This suggests that these are pH loving species.

Discussion

Species richness and diversity indices

Biodiversity is a natural resource, which closely links to the economic well-being of any country or any region. Narapani-Masina landscape is small but rich in biodiversity (460 vascular species). The possible reasons may be large variation in topography, aspect and climate within the area. Panthi and Chaudhari (2002) listed 500 species of angiosperms from the Arghakhanchi district. The present results suggest that further

Table 3. Results of model test of PerMANOVA analysis between environmental variables and vegetation community composition in Narapani-Masina landscape, west Nepal (R^2 shows each variable's share of the total variation in the data set).

Parameter	Df	F value	R^2	Pr (>F)
Alt	1	**7.12**	**0.07**	**0.001**
Aspect	3	**1.52**	**0.05**	**0.003**
RRI	1	1.21	0.01	0.132
pH	1	1.02	0.01	0.439
N	1	1.01	0.01	0.441
P	1	**1.37**	**0.02**	**0.046**
K	1	**2.52**	**0.03**	**0.001**
Residuals	25		0.26	

*Bold type face indicates statistically significant ($p < 0.05$).

Table 4. The table of DCA of species composition.

	DCA1	DCA2	DCA3	DCA4
Eigen value	0.35	0.18	0.18	0.16
Decorana value	0.36	0.2	0.17	0.16
Axis length	3.23	3.04	2.37	3.32

Table 5. Value of CCA1 and CCA2.

	CCA1	CCA2
Eigen value	0.32	0.16
Proportion explained	0.27	0.14

Table 6. CCA biplot scores of species composition against environmental variables and variance inflation factor (Vif. CCA).

Variables	CCA1	CCA2	Vif. CCA
Aspect North	0.07	**0.35**	2.09
Aspect South	−0.24	**−0.96**	2.97
Aspect West	0.14	**0.28**	2.39
Alt	**0.99**	−0.05	2.09
RRI	0.15	0.39	1.45
pH	−0.19	**−0.30**	1.47
N	**0.51**	−0.27	2.01
P	**0.24**	−0.08	1.47
K	0.39	**0.56**	2.30

*The bold figure indicates the statistically significant ($p < 0.05$).

detailed exploration of this biodiversity-rich area is necessary for documentation and conservation purposes.

We found the values of Shannon-Wiener and Simpson indices higher in the forest of east and west aspects. Diversity is the aggregate form of species richness and evenness and high diversity indices indicate the characteristic of more diverse communities. If the species are uniformly distributed, then the diversity value would be high (Southwood and Lineacre 2015). The species richness and altitudinal range of the south face is more in comparison to other aspects. Generally, the north slope aspect of hills in Nepal is moist, and the south is drier, which results in higher species richness in the north slope aspect than the south in Manang valley (Panthi et al 2007). According to Auslander et al (2003), south-facing slopes may receive six times more the amount of solar radiation than north-facing slopes in the northern hemisphere. The growth rate of plants in the south-facing slope aspect may be less than the North aspect due to high solar radiation and less moisture. It is also supported by Maren et al (2015) because water plays a deterministic role in the composition, structure, and density of plant communities (Kutiel and Lavee 1999). We found a high value of species richness and diversity indices at the east and west faces which may be due to the presence of sufficient both moisture and solar radiation. It confirms that water and solar radiation play a leading role in species richness and species distribution in different aspects of any landscape or all continents or countries. The species diversity is less in south aspect even there is high species richness, and the diversity is higher in east and west aspects due to their comparatively high evenness of species.

Correlation among the variables

According to the results of the correlation analyses, altitude shows a significant positive correlation with soil total nitrogen, phosphorus, and potassium. Qasba et al (2017) also reported that available N, P, and K showed a significantly positive relation with altitude. According to Anic et al (2010), the soil nutrients also showed a significant negative correlation with elevation in the Andes (1970–3330 m), Central Chile. Similarly, there is a negative correlation of pH with soil total nitrogen, available phosphorus (P_2O_5), and extractable potassium (K_2O) (Khadka et al 2016). The elevation and other climatic factors are responsible for controlling the carbon, nitrogen, and other minerals concentration (Shedayi et al 2016). The above- and belowground stocks of the total nitrogen increase significantly with elevation. The decrease in soil

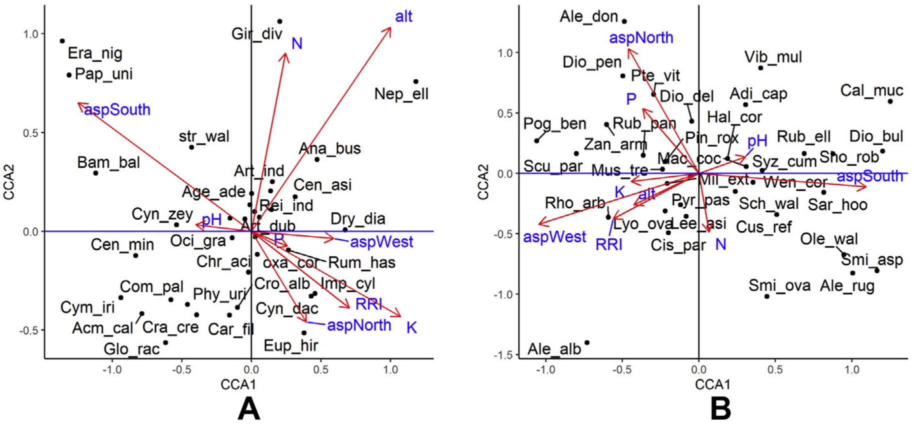

Figure 5. Canonical correspondence analyses (CCA) plot showing the effect of significant environmental variables on the species richness of (A) Herbs & (B) combined form of climber, ferns, shrubs and trees.

temperature by 1°C with the altitude showed a significant inverse relationship of nitrogen stocks (decrease rate of 1 $\mathrm{Mg \cdot ha^{-1}}$) in soil (Vieira et al 2011). This increasing soil water content and lowering soil temperature help to decreases in soil N mineralization and nitrification rates which ultimately makes the high content of soil nitrogen due to the low rate of litter decomposition (Zhang et al 2012; Måren et al 2015). The farmland was also found nearer to the forest in some parts of the study area where some portion of chemical fertilizer may reach in the forest. These reasons support the positive relation of soil nitrogen, phosphorus, and potassium with the altitude of this research.

Species richness showed negative correlations with all environmental variables but significant with only altitude and nitrogen. Similarly, species richness showed a negative relationship with elevation (Bhandari and Zhang 2019) and phosphorus (Riesch et al 2018). High availability of P favors a few competitive species that results in the exclusion of low productive species which lose out in the competition for light (Hautier et al 2009). The nutrient content of soil (C, N, P, K, etc.) varies with the topographic aspect and altitude with vegetation (Bangroo et al 2017).

All four aspects of the hill showed variable responses with respect to environmental factors. The south slope aspect has a significant negative, but the west slope aspect has a positive correlation with RRI. Similarly, the east and west aspects show statistically negative, but the south slope aspect shows a positive relationship with soil pH. Soil pH shows minor changes through the elevation gradient (Saeed et al 2014).

Effect of environmental variables on species richness

Altitude functions as the main decisive factor of ecosystem properties and processes in the mountains (He et al 2016) and altitude variations determines slope and aspects on land. The model result of regression showed that altitude had a significant effect, but the slope aspect has no significant influence on species richness. The studied altitudinal ranges was varied between the four slope aspects. Each altitudinal range showed a significant unimodal richness pattern, but the peak of maximum richness differed between them. However, the unimodal nature of species against elevation was stronger in north and west than in other slope aspects. Many researchers (Rohde 1992; Bhattarai and Vetaas 2003; Bhattarai et al 2004; Grau et al 2007) reported that altitude showed a unimodal effect on species richness. The elevation having maximum species richness depended on altitudinal range, plant taxa etc. (Grau et al 2007). Generally, a right skewed altitudinal species richness pattern shows negative correlations and a left skewed pattern shows positive. When the gradient is shorter, a hump-shaped pattern of longer elevational gradients would change to a monotonic decreasing (Nogués-Bravo et al 2008) or linearly increasing trend (Greatness and Vetaas 2002) or with increasing spatial scale of extent, the richness pattern changes from a monotonic to a hump-shaped pattern (Manish et al 2017). Most of the unimodal relationship between species richness and altitude are right skewed. The right skewed pattern in north and east aspect and left skewed pattern in west aspect suggest that no particular type of skewness present in the unimodal pattern in this study. There is evidence of a unimodal pattern in many regions at smaller spatial scales such as landscape and local gradients (Ooman and Shanker 2005). The hard-boundary effect (Colwell and Lees 2000), which results less area on top of the hills (Hua 2004) and overlapping of species of both lower and higher elevation range declares the unimodal nature is generally fit to describe the relationship between species richness and elevation well.

RRI score is an aggregate of latitude, slope, and aspect of any mountainous area. Spatial variation in slope and aspect function as determinants of vegetation pattern, species distribution, and ecosystem processes in many mountainous environments (Bennie et al 2008). RRI showed no significant linear relations with species in all aspects. The microclimatic conditions on the slope of an area vary dramatically, which may affect the biology of organisms at all levels. The distinct climate conditions and soil nutrients through the altitude gradient of slopes can influence the aboveground biomass and species richness (Bhandari and Zhang 2019).

The soil variables like pH, N, and K showed non-significant, linear relations with species richness in all aspects and total landscape. But, soil P showed a significant unimodal relationship with species richness in the north slope aspect but non-significant linear structures in other slope aspects. The soil nutrients are related to nutrient cycling through leaf litter fall and decomposition (Hicks and Frank 1984), and the litter decomposition has resulted from soil moisture, soil temperature, soil micro-organisms, and other factors. The nutrients reach the soil from the air through physical or biochemical processes or were present in the rocks. So, the slope aspect has no direct role in mineral distribution.

Litter fall regulates the accumulation of soil organic matter, the input of the nutrients, nutrient replacement, maintenance of biodiversity and other ecosystem functions in natural vegetation (Giewta 2020). Generally, dry litter decomposes more slowly in dry areas than in moist areas. At suitable moisture conditions, increasing temperature results in an exponential increase in decomposition rates (Salahab and Scholes 2011). The south aspect is drier than the north slope aspect in Nepalese Himalaya. The moisture and suitable temperature of the northern slope aspect helps in continuous leaf litter decomposition, which results in high nutrients content on the soil. Plant available soil K, P, and N are not limiting the productivity at south with respect to north-oriented slopes, because soil available water functions as the primarily limiting factor for plant productivity (Gong et al 2008). Generally, north-facing slopes are connected with higher biomass, coverage and height, and species diversity than south facing slopes (Xue et al 2018; Yang et al 2020). We can say that altitude is the main factor affecting species richness. But, aspect indirectly affects species richness by creating a dry or moist environment and altering the rate of leaf litter decomposition.

Environment Species Composition

The result of permutational multivariate analysis (PerMANOVA) suggested that altitude, aspect, phosphorus, and potassium showed a significant relationship with species composition. Anderson (2006) stated that distance-based tests are robust and useful for detecting real differences in the species spread.

The survival of plant species generally depends on nutrient requirements. Different plant groups may show different responses to nutrient availability (Ellenberg 1988; Johnson and Leopold 1994). Species scores are expressive forms of the united effect of all projecting variables represented by the controlled axes. The first eigenvalue of CCA is equal to the maximized dispersion of species scores along the first CCA axis (Ter Braak 1986). In the CCA diagram, altitude, soil N, and P are correlated with the first axis and show positive relation to each other. The canonical correlation r-value shows the effects of variables on species distribution in the following order: altitude $>$ N $>$P. The high score bearing species: like: *Zanthoxylum armatum, Macaranga denticulata*, etc. are present in sites higher in N and also show positive responses to altitude. Similarly, species like *Fragaria nubicola* and *Centella asiatica,* which have medium scores, are found at the sites having a high content of phosphorus. This result shows that soil nitrogen is more strongly correlated to altitude than phosphorus. Soil moisture is the main cause of the nitrogen effect in soil (Gornish and Miller 2015). The moisture generally increases with elevation in Nepal. The high nitrogen content makes the soil more acidic in combination with high moisture (Deutsch et al 2010; Ying et al 2012). This may a cause of the decreasing trend of species richness toward higher elevations. Vegetation composition are affected by nutrient limitation, which is governed by low soil temperatures and influenced by soil moisture conditions in Himalayan region (Drollinger et al 2017). The plants require (on a mass basis) about ten times more N than P to promote balanced plant growth (Aerts and Chapin 2013).

The canonical correlation value of potassium ($r = 0.56$) and pH ($r = -0.30$) shows that they have more scores on the CCA 2 axis. The moderately positives score bearing species like; *Barleria cristata, Imperata cylindrica,* show high dominancy at high potassium-containing sites. The negative score bearing species on CCA2 are *Evolvulus nummularius, Setaria parviflora,* shows positive response with pH and are present at high pH sites. The linearly decreasing pattern of pH and the increasing patterns of nitrogen content against altitude show that the high altitude sites have high N content and low pH value. Inouye et al (1987) also found a negative relationship between soil nitrogen and species richness. Crawley et al (2005) experimentally proved that species richness increases sharply with increasing pH (6-7) but decreases along with the addition of phosphorus and potassium. The presence of more nitrogen in soil may be the main cause of the loss of plant biodiversity in terrestrial ecosystems (Dise 2011). Similarly, the species *Inula cappa* and *Gnaphalium affine* have negative scores on CCA2 and are present at the high RRI score bearing area.

The comparative test of aspect on species richness by ANOVA and species composition by PerMANOVA shows that slope aspect has a significant effect on species distribution, not on species richness. The CCA also describes the relation of slope aspects with species and other environmental variables. The south slope aspect shows a strong role in species distribution than other slope aspects. The species: *Euphorbia hirta, Justicia adhatoda, Diospyrus spp, Cyanotis vaga, Mallotus philippensis* have high dominancy in the south slope aspect. Other north and west aspects show a negative relationship with pH and a positive with RRI and potassium. The south slope aspect has a positive relation with only soil pH, which is also proved by the negative correlation of species richness with altitude and nitrogen content. The topographical factors (elevation and aspect) affect mountain forests through their direct influence on radiation and moisture (Maren et al 2015)

The accurate estimation of soil nutrients helps to understand the interaction of biogeochemical cycles with the global climate (Shaw et al 2002). Changes in climatic conditions (temperature and precipitation) along altitudinal gradients can influence nutrient content (Fisher et al 2013). The wild plants get nitrogen content from the soil nutrients via the nitrogen fixation and nitrification processes.

Some species are present at N, P, and K rich sites at high altitudes, and some are present at high pH value at low elevations. The nutrients (N & P) absorption efficiency of plants depends on latitude, mean annual temperature, and mean annual precipitation (Yuan and Chen 2008). This study shows that the nutrient requirement of plants varies according to species, plant age, habitat, and soil type, but a few species have a positive response towards a high concentration of nutrients.

Conclusions

The Narapani-Masina landscape is inhabited by at least 460 vascular plant species, and there is a considerable variation in slope aspect wise species richness and nutrient contents. The species richness showed a unimodal pattern against altitude, but the slope aspect did not have a significant impact on species richness and diversity indices. The increasing trend of soil N, P, and K with altitude showed negative relations with species richness. CCA analysis gave ordination axes that were strongly correlated to environmental variables: elevation, soil N, K, and south aspect and related to the pattern of species distribution. The plant species that are present in the high concentrations of nitrogen, phosphorus, and potassium in the soil also show positive responses to altitude. On the other hand, the species which are present in soil with high pH (especially at the south aspect) showed a negative relation with elevation. In mountainous regions, both altitude and slope aspects show effects on species composition rather than species richness through the changes in edaphic and climatic factors.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Appendix 1. The impact of aspect wise environmental parameters on species richness obtained by generalized linear model (GLM).

	South		East		North		West		Aggregate	
	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2
Altitude	2	0.32	2	0.46	2	**0.64**	2	**0.59**	2	**0.67**
RRI	1	0.09	1	0.36	1	0.1	1	0.02	1	0.02
pH	1	0.04	1	< 0.001	1	0.08	1	< 0.001	1	<0.001
Nitrogen	1	0.12	1	0.11	1	0.26	1	0.02	1	0.09
Phosphorus	1	0.05	1	0.14	2	**0.58**	1	0.005	2	0.1
Potassium	1	0.04	1	0.003	1	0.03	1	0.02	1	0.005

*The bold figure indicates statistically significant ($p < 0.05$).

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Research Article

INTERPOLATED ALTITUDINAL SPECIES RICHNESS IN ARGHAKHACHI DISTRICT OF NEPAL

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ABSTRACT

The magnitude of climatic variables over space and time determines the altitudinal variation of species richness. The present study has been carried out to determine the vascular plant species richness patterns along with altitude in the Arghakhanchi district (27º 45' to 28º 06' N and 80º 45' to 83º 23' E), West Nepal. The published literature related to the altitudinal distribution of vascular plant species in Arghakhanchi district was collected and enlisted a total of 597 species. The altitudinal range of the Arghakhanchi district was 200-2300 meters above sea level (masl) which was divided equally into 21 bands of 100 m each. The total number of vascular species that occurred at each 100 m contour elevation was considered as the species richness. The objective of this study was to find the vascular plant species richness pattern in Arghakhanchi district concerning altitude and climatic variables. The generalized linear model (*GLM*) was applied to the total species richness against altitude, annual mean temperature (AMT), and mean annual rainfall (MAR). Total vascular species richness showed a statistically significant unimodal pattern with a maximum richness of 471 species at 1300 masl ($r^2 = 0.91$; $p < 0.001$). Likewise, gymnosperm, dicot, monocot, and pteridophyte species richness showed a highly significant unimodal altitudinal richness pattern. Altitudes of modeled maximum species richness were found varied according to the taxa.

Keywords: Climate, Contour elevation, *GLM,* Linear, Unimodal

INTRODUCTION

Altitudinal variation in species richness is clearly expressed by area (Wang *et al*., 2007), disparity of temperature and rainfall (Stevens & Fox, 1991; Khan & Ahmed, 2015), complex topography (Grytnes, 2003), aspect (Sharma *et al.* 2014), and soil composition (Dölarslan *et al*., 2017). The relationship between altitude and species richness shows three types of patterns: monotonically increasing, decreasing, and hump-shaped (Rahbek, 1995; Song & Cao, 2017). More than 50 % of researches related to altitudinal richness showed a unimodal pattern with high richness at an intermediate altitude (Rahbek, 1995; Oommen & Shankar, 2005). There are numerous studies on species richness in Nepal which reported hump-shaped patterns with maximum richness at mid altitudes (Grytnes & Vetaas, 2002; Bhattarai *et al*., 2004; Grau *et al*., 2007; Baniya *et al*., 2010). This hump-shaped pattern might not be prominent, particularly for small grain sizes and along incomplete gradients (Rahbek, 2005).

Mountains, an ideal natural system, provide gradients of climate and other environmental variables (Ghazal, 2015), harbor number of species (Gaston, 2000; Khan & Ahmed, 2015) and environment to explore drivers determining species richness patterns (Körner, 2007) due to wider altitudinal range and complex topography at a short space. Stevens (1989), in "seasonal variability hypothesis" indicated that greater the seasonal temperature variations at high altitudes higher the species tolerant to greater climatic disparities. Biodiversity is not homogeneously dispersed across the earth (Khan *et al.,* 2016). The prime factors such as altitudinal gradients, aspects and the physical environment (Korner, 2000; Sharma *et al*., 2014), climate, productivity, anthropogenic influences, evolutionary history, physiological traits and biotic interactions (Webb & Gaston, 2003; Zhang *et al.,* 2016) modify local microclimate and determine spatial and temporal distribution, abundance and richness patterns of organisms.

Species richness is the simplest and most frequently used (Brown *et al.,* 2007), predictable and fundamental measure of the community at both local and regional levels of diversity (Gotelli & Colwell, 2001). The height, diameter, and density of the species differed along the altitudinal gradient and showed a species-specific trend (Rana *et al*., 2016). The distribution range of species and species richness pattern is changeable concerning time and space (Gillman & Wright, 2006). Species richness pattern appears as a combined picture of many ecological variables. The altitudinal range is the most important variable among all models at different scales which shapes patterns (Xu *et al.,* 2017).

The altitude itself represents a combination of other topographical factors such as aspect and slope (Holland &

Steyn, 1975), climatic variables like temperature, rainfall, etc. and edaphic properties (Ramsay & Oxley, 1997). Generally, the area decreases with the increase of altitude in the Himalaya region. Larger the area greater will be the number of species occupied (Lomolino, 2001) due to availability of more habitats or space, biogeographical provinces (Williams, 1964), and greater heterogeneity (Wills *et al*., 2005). According to Bhattarai (2017), broad-scale explanatory variables cannot detect richness patterns at the finer scales and vice versa. Monotonic, unimodal, or multimodal patterns are common at local scales whereas unimodal pattern is favored for regional scales when multiple local replicates are aggregated (Oommen & Shanker, 2005). Even within the same mountain, organisms inhabiting different slopes may possess distinct diversity patterns and the underlying mechanisms (Shuai *et al*., 2017).

Climatic factors vary with altitude, influence species richness patterns (Bhattarai, 2017). The physiological activities as productivity and life-form diversity are determined by the interactions between temperature and precipitation (O'Brien, 2002). Measurable changes in climate may occur only at distances greater than 100 km (O'Brien *et al*., 1998), but environmental variation appears along the 100 m altitudinal differences (Bhattarai *et al.* 2004).

Variation in species richness with altitude either connected with the rate of change of eco-physiological processes or due to the change in temperature and productivity (Rahbek, 1995). Precipitation is relatively a complex gradient (Adler & Levine, 2007; Lomolino, 2001), that showed a spatial variation i.e., enhanced in some regions and decreased in some other mountainous regions. The altitudinal pattern in species richness has opened up ample options to find out the general mechanisms responsible for the distribution of biodiversity (Grytnes & McCain, 2007).

Nepal is a part of the central Himalayas where many unique biodiversity areas are yet to explore and proper conservation may be necessary. Arghakhanchi is one of the 77 districts, lies in the fifth province in Nepal and the high biodiversity zone of the mid-mountain region. The Humpbacked species richness-curve is a contingent rule for Community Ecology (Graham & Duda, 2011) which may be based on primary or secondary data. Different environmental factors act as the main driver of species richness at large and small areas (Vetaas & Ferrer-Castan, 2008). Thus this study puts the hypothesis that vascular species richness follows the unimodal pattern with altitude as well as climatic variables.

The main aim of this study was to determine the altitudinal species richness pattern of vascular and its derivatives richness pattern and relation with climatic variables.

MATERIALS AND METHODS

Study area

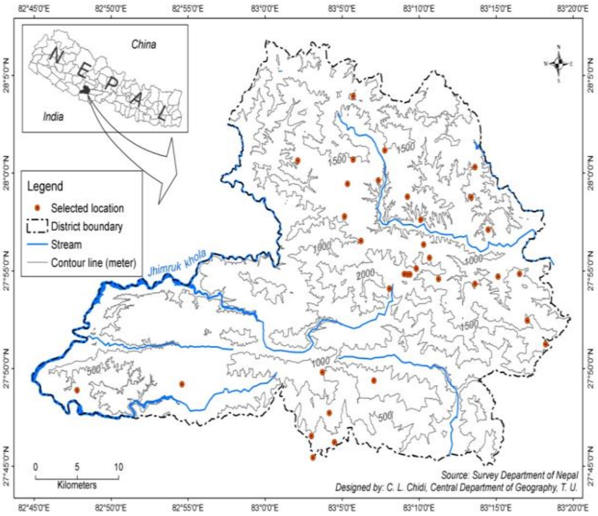
Arghakhanchi, one of the beautiful hilly districts, is located in Providence No. 5, west part of Nepal. It ranges from 27º45' to 28º06'N latitude and 80º45' to 83 º 23' E longitudes (Map. 1). It covers an area of 1193 km² and a population of 197,632 (CBS, 2012). About 68 % of this district lies within the Mahabharat range and rest in the Siwalik hills. The altitude of this district ranges from 240 to 2515 masl (AEPC, 2016)). Physiographically, this district has four zones: lower tropical (less than 300 masl covers 0.2 %), upper tropical (300-1000 masl covers 51 %), subtropical (1000-2000 masl covers 49 %) and temperate zone (above than 2000 masl covers 0.2 %) (CBS, 2012). The average maximum and minimum temperatures range are between 25-27 °C in May-July and 5-7 °C in January (DHM, 2017). The average annual rainfall of this district remains around 1750 mm (MOAC/FAO, 2011). According to MOAC (2011), out of the total 119,300 ha land of the district, cultivable land occupies 45,712 ha (38 %), forested land occupies 66,800 ha (56 %), river and ponds occupy 5768 ha (4.8 %) and the residential area covers 1020 ha (0.85 %).

Lowlands, the southern part of Arghakhanchi, consists of the lower tropical forest of *Shorea robusta*, *Dalbergia sissoo, Lagestroemia parviflora, Terminalia alata,* etc. Churia sal forest lies between 300-1000 masl, dominated by *S. robusta, T. alata, Cassia fistula, Bauhinia variegata*, etc. In the middle belt, hill Sal forest is present with *Schima wallichii, Syzygium cumini*, *Pinus roxburghii*, and *Pyrus pashia*. In the northern aspect (below 1000 to 1500 masl), the broad-leaved forest (*Diospyrus malabarica, Rhododendron arboreum, S. wallichii*, *Catonopsis indica*) is intermixed with *P. roxburghii* and *S. robusta*. Between 1500-2000 masl, broad-leaved forest (*R. arboreum, S. wallichii, P. roxburghii, Myrica esculenta)* is present. The uppermost region (above than 2000 masl) in this district, the *Rhododendron - Quercus-Maesa* mixed forest is present which is dominated by *R. arboreum, Q. semecarpifolia, Q. glauca, M. esculenta*, *Zanthoxylum armatum* with bushes of *Maesa chisia,* etc (Panthi, 2005).

Study design and data collection

This study analyzed plant and climatic data collected from secondary sources described herein. Altitudinal distribution range of plants in the Arghakhanchi district was derived from different literature (Acharya *et al.* 2015; Fraser-Jenkins *et al*., 2015; Fraser-Jenkin & Kandel, 2019; Panthi, 2005; Panthi & Chaudhary, 2002; Pokhrel, 2013; Poudel *et al*., 2010). The altitudinal range (200-2300 masl) of Arghakhanchi district where plants were reported from was divided equally into 21 bands each with 100 masl intervals each. The species present in each 100 masl contour was considered as the species richness.

Similarly, species richness was categorized into dicot, monocot, gymnosperm, and fern or pteridophyte species richness. This is a macro-scale study that covered an entire altitudinal range of Arghakhanchi district.



Source: Survey Department of Nepal
Designed by: C. L. Chidi, Central Department of Geography, T. U.

Map 1. Arghakhanchi district with botanically explored sites

Annual mean temperature (AMT) and mean annual rainfall (MAR) data for Arghakhanchi district and surrounding areas obtained through published literature (MoAC, 2011; AEPC, 2016; DHM, 2017) were utilized in this study (Table 1). AMT per 100 altitudinal zone in this study was estimated after significant linear regression model ($R^2 = 0.99; p < 0.05$) at a lapse rate of 0.5° C/100 m (Bhattarai *et al.*, 2004). Rainfall was not a simple linear function of altitude, therefore a cubic smooth spline with 4 degrees of freedom was applied through the GAM model (Guisan *et* al., 2002) to estimate total annual rainfall at each 100 m altitudinal bands.

Data analysis

The correlation among variables was estimated by using Pearson's Correlation method (Kassambara, 2018). The regression analysis of species richness against altitude was done by using the GLM (Hastie & Pregibon, 1993). Likewise, regression analysis of species richness was done against climatic variables such as MAR and AMT. The quasipoisson family of error distribution was applied to remove overdispersion. All these analyses were done in R (R Core Team, 2019).

RESULTS

Species richness of vascular plants

A total number of 597 vascular plant species (belonging to 452 genera and 190 families) were recorded in Arghakhanchi district (Table 2). The dicots consisted of 83.9 % species (157 families, 381 genera, and 501 species) while the monocot consisted of 13.9 % (24 families, 62 genera and 83 species), gymnosperm consisted of 0.5 % (2 families, 2 genera and 3 species), and pteridophytes (ferns) consisted of 1.7 % species (7 families, 7 genera and 10 species) as summarized in Table 2.

Table 1. Climatic records of Arghakhanchi and surrounding areas from 1994-2013 AD (MoAC, 2011; AEPC, 2016; DHM, 2017)

Place	Alt (m)	Lat (°)	Lon (°)	Amt (°C)	Mar (mm)
Taulihawa	94	27.33	83.04	24.3	1357
Bhairahawa	109	27.31	83.26	24.2	1630
Patharkot	200	27.46	83.03	23.5	1467
Butwal	205	27.42	83.28	24	2203
Ghorai	701	28.03	82.3	22.1	1572
Tulsipur	725	28.08	82.18	22.4	1650
Bijuwar	823	27.52	82.52	22.2	1272
Tansen	1201	27.52	83.32	18.4	1912
Libang	1270	28.18	82.38	18.7	1312
Salyan Bazar	1457	28.23	82.1	19.2	987
Tamghas	1530	28.04	83.15	17.5	1897
Khanchikot	1760	27.56	83.09	16.4	1775

* *Alt- altitude, Lat- latitude, Lon- longitude, Amt- annual mean temperature; Mar- mean annual rainfall*

Table 2. Taxonomic diversity of vascular plants in Arghakhanchi district

Taxa	**Species richness**					
	Herb	Shrub	Tree	Climber	Fern	Total
Dicot	188	125	138	50	–	501
Monocot	70	4	1	8	–	83
Gymnosperm	–	–	3	–	–	3
Pteridophyte	–	–	–	–	10	10
Grand total	258	129	142	58	10	597

Correlation among variables

All vascular taxa showed positive but not significant relationship ($r = 0.11$ to $0.26, p < 0.001$) with altitude. Similar there was positive relationship between rainfall and vascular taxa except for monocot and gymnosperm (Table 3). But, the vascular taxa showed a negative and not significant relationship with temperature.

Species richness pattern of vascular plants against altitude

The species richness of vascular taxa (dicot, monocot, gymnosperm, and ferns) increased up to a certain altitude then declined afterward showing a unimodal distribution pattern, as indicated by a statistically significant second-order model in *GLM* (Appendix 1). The total vascular species obtained the maximum modeled species 471 (R^2=0.914 and $p < 0.001$) at peak elevation 1300 m (Fig. 1a). Similarly, the richness of dicot taxa (Fig. 1b), monocot (Fig. 1c), Gymnosperm (Fig. 1d), and ferns (Fig. 1e) made a hump-shaped structure against altitude.

Table 3. Correlation among species richness, altitude, temperature, and rainfall ($p < 0.001$)

	Altitude	Temp	Rainfall	Gymno	Pterido	Monocot	Dicot	Total spp
Altitude	1	-	-	-	-	-	-	-
Temperature	-1	1	-	-	-	-	-	-
Rainfall	0.8	-0.8	1	-	-	-	-	-
Gymnosperm	0.26	-0.26	0.06	1	-	-	-	-
Pteridophytes	0.23	-0.23	0.12	0.89	1	-	-	-
Monocots	0.11	-0.11	-0.02	0.9	0.96	1	-	-
Dicot	0.2	-0.2	0.11	0.86	0.98	0.96	1	-
Total species	0.19	-0.19	0.09	0.87	0.98	0.97	1	1

Temp = temperature, Gymno = Gymnosperm, Pterido = Pteridophytes, spp = species

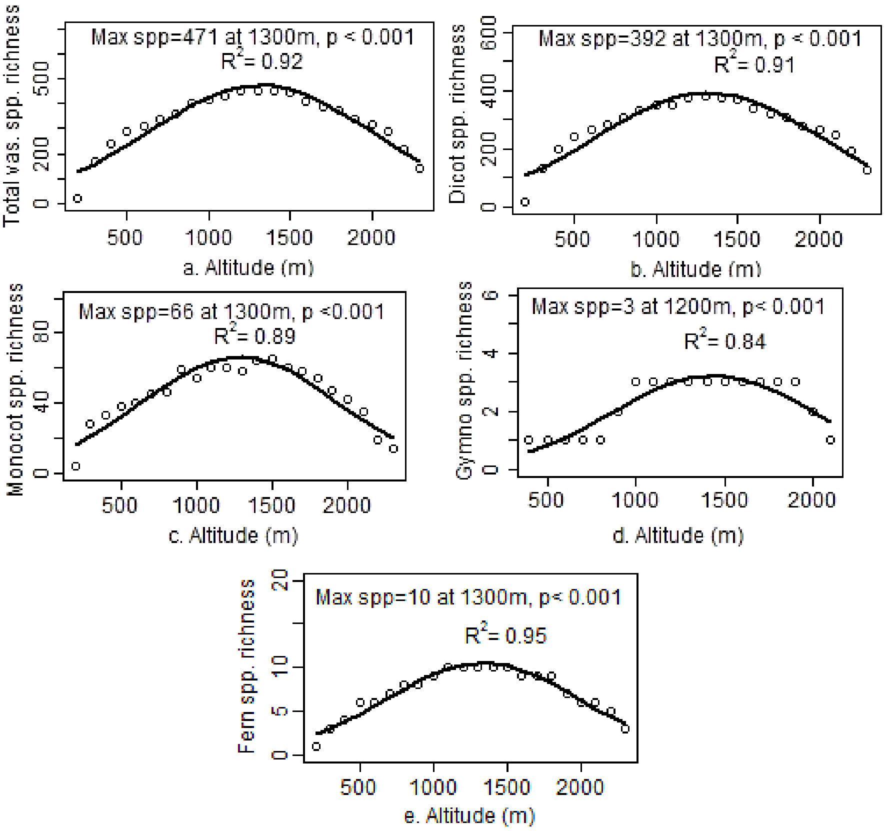


Fig. 1. Estimated response curves by GLM model, which portrays the relationship between altitude and species richness of (a) total vascular species (b) dicot (c) monocots (d) gymnosperm and (e) ferns

Species richness pattern against climatic variables

The richness pattern between vascular species and climatic variables (temperature and rainfall) was also unimodal, which was indicated by a statistically significant second-order term in *GLM* (Appendix 1). The species richness increased along with the annual mean temperature (AMT) and decreased after optimum value 18.2 ^{0}C (at 1300 m) showing unimodal structure (Fig. 2a) bearing maximum modeled species 472 ($R^2=0.914$, $p < 0.001$). Similarly, the species richness showed unimodal with plateau structure with mean annual rainfall (MAR) as depicted in Fig. 2(b) with maximum modeled species 432 at optimum value 1805.4 mm (at 900m, $R^2 = 0.64$ *and* $p < 0.001$).

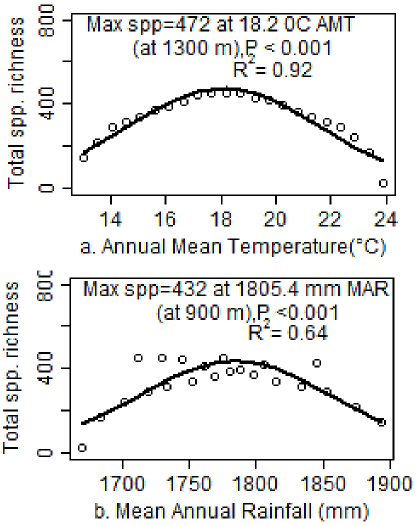


Fig. 2. Estimated response curves by the generalized linear model (*GLM*), which portrays the relationship between total species richness and (a) annual mean temperature (AMT) and (b) mean annual rainfall (MAR)

DISCUSSION

Species richness

Arghakhanchi is a biodiversity-rich district in Nepal due to the occurrence of 597 vascular species belonging to 452 genera and 190 families. This district covers 0.81 % of the total land area of Nepal (AEPC, 2016). It occupies 11.06 % of the total flowering species of Nepal (5309 species as reported by Rajbhandari *et al.*, 2017) and 1.87 % of the total pteridophytes (534 species reported by Fraser-Jenkins *et al.*, 2015) in Nepal. However, Panthi & Chaudhary (2002) reported a total of 501 flowering plants from the Arghakhachi district. This number does not include the pteridophyte species. He increased the number of flowering plants as well as pteridophyte and may represent an increasing number of exploration from this district as well as other parts of the country. Based on these species we can say that the Arghakhanchi district rich in biodiversity though it is small in area. The species dominated and confined here are mainly of tropical to temperate origin.

Correlation among variables

There was a weak positive correlation among species richness variables of vascular taxa with altitude. This correlation was strong among species richness themselves: Gymnosperm, Pteridophyte, and Monocot richness. The latter strong correlation among species would be the higher proportion of these species in the total richness. The result of empirical fern species richness and altitude (Jeyalatchagan *et al*., 2019) and interpolated plant species richness with altitude (Grytness & Vetaas, 2002) was also found to be a positive relationship. The positive relationship between altitude and species richness may be due to an extend of altitude as well as a limit of the mountain. Since the altitudinal extent of Arghakhanchi was 200 to 2300 masl. Thus the positive relationship between altitude and richness was justified.

Similarly, rainfall showed a positive but temperature expressed a negative relation with species richness. Zhang *et al.* (2016) also found similar results that annual mean temperature (AMT) showed negative but rainfall showed a positive correlation against species richness at the temperate region of China. According to Sharma *et al.* (2009), altitude and climatic factors are the main regulating factors of distribution and show significant negative relation with species richness. The altitude itself represents a complex combination of related climatic variables with other environmental properties. Generally, environmental variables are measured at different units of scale. Each of these variables hardly shows a simple and direct linear relationship with species richness (Pitcher *et al.*, 2012). This means species richness may show nonlinear pattern with environmental variables.

Species richness pattern

From this study a significant unimodal species richness pattern against altitude was found. Similar patterns were observed for vascular plants (Grytness & Vetaas, 2002; Bhattarai & Vetaas, 2006), Bryophytes (Grau *et al.*, 2007), lichens (Baniya *et al.*, 2010), herbaceous plants (Bhatta *et al.*, 2018), and environmental variables (Pokharel *et al.*, 2018), etc. in central Nepal. The general unimodal species richness pattern was justified. During interpolation, the species present in an altitudinal band may create an artificial decrease in species richness towards both ends of the altitudinal gradient (Grytness & Vetaas, 2002). That may impose an artificial unimodal richness pattern. However, the altitudinal range of individual species in this study was beyond the extent of altitude of the landscape. Thus obtained unimodal richness pattern of this study is not an artifact. This result concludes that species richness of vascular plants has a unimodal pattern to altitude and climatic variables of the mountainous area, which was well portrayed by the fitted *GLM*.

In this study, greater number of species was present at 1200-1400 masl, which is less (1500 to 2500 for flowering plants and 1900 m for ferns) than overall Nepal (Grytnes & Vetaas, 2002). According to Bhattarai & Vetaas (2006), the range of species remains wider at mid-elevation and narrower at the gradient endpoints. Colwell

& Hunt (1994) explained that the mid-elevation peaks in species richness were formed by an increase of overlapping of species range towards the center of the domain. This helps to conclude that more or less mid-altitude of the overall distribution range bear maximum species richness.

The unimodal pattern of species richness may also be connected to human disturbance as well as disturbance associated with other factors. Arghakhanchi falls under the middle mountain range where human dominance is generally more than in higher altitudes. Middle mountain provides lots of opportunities and has been providing diverse ecological services to human from ethnomedicines (Rai & Singh, 2015) to several others (Bhandari *et al*., 2018). That may support a finding of a unimodal relationship with altitude.

The climatic variables (temperature and rainfall) for total species graphed characteristically showed a significant unimodal pattern. Bhattarai *et al.,* (2004) found fern richness monotonically decreased towards higher (lowland) and lower (highland) values of the Potential Evapotranspiration (PET) gradient. The changes in temperature systematically alter the relationship between the biodiversity and ecosystem functioning via a temperature-driven shift in the strength of selection and complementary effects (Garcia *et al.*, 2018).

Similarly, species richness showed more strong correlation with temperature than rainfall, which was supported by the previous study of Griffiths *et al.* (2013). Temperature and rainfall variation occurs due to the altitudinal difference of mountains as well. Precipitation, a relatively complex pattern (Lomolino, 2001), is enhanced in some regions and decreased in other areas in the mountainous region. It has a significant impact on the productivity and species richness of the community (Yan *et al.,* 2015). The species richness of annuals, as well as perennial plants, may increase significantly with increasing annual and seasonal precipitation. Hence, Arghakhanchi lies relatively at the higher biodiversity zone in Nepal, favored by moderate disturbance, higher AMT, and MAR that support unimodal richness patterns.

The altitudinal distribution range was the most important predictor at all scales (Vetaas & Ferrer-Castan, 2008). It was supported that low peak elevation (1200-1400 m) in this study was proportional to less altitudinal distribution range (200-2300 m) of Arghakhanchi in comparison to overall Nepal (86 to 8848 m). Thus it is similar in species richness pattern but numerically different in peak elevation having the highest number of species to overall Nepal. The range margins of species in the gradient are determined directly or indirectly by unsuitable extremes of climatic factors (Bhattarai *et al.*, 2004) or geographical hard boundaries.

CONCLUSION

This study reported 597 vascular species in the Arghakhanchi district. The species richness showed a positive correlation with altitude and rainfall but a negative correlation with temperature. The species richness showed significant unimodal response with altitude, temperature, and rainfall. However, altitudes of the highest richness were found significantly different with taxa and less than the general pattern as purposed for Nepal.

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APPENDIX 1. Complete regression of species richness by use of generalized linear model against altitude and climatic variables in Arghakhanchi district (R^2= *0.64* to *0.95*, $p < 0.01$)

Model	Predictor	Response	D_f	ResidDev	D_f	Deviance	F	Pr(>F)
0	Altitude	Total species	22	362416				
2			**20**	**327**	**2**	**362088**	**14782**	**< 2.2e-16**
0	Altitude	Dicot species	22	245523				
2			**20**	**280**	**2**	**245243**	**11634**	**< 2.2e-16**
0	Altitude	Monocot	21	6213.5				
2			**19**	**27**	**2**	**6186.5**	**2497**	**< 2.2e-16**
0	Altitude	Gymnosp	17	15.1111				
2			**15**	**1.4605**	**2**	**13.651**	**72.262**	**1.993E-08**
0	Altitude	Ferns species	21	147.818				
2			**19**	**1.92**	**2**	**145.9**	**796.39**	**< 2.2e-16**
0	AMT*	Total spp	21	270206				
2			**19**	**170**	**2**	**270036**	**19461**	**< 2.2e-16**
0	MAR^a	Total spp	21	270206				
2			**19**	**376**	**2**	**269831**	**7156.4**	**< 2.2e-16**

**AMT- Annual mean temperature, ^{a}MAR – Mean annual rainfall, all bold entries were accepted model*

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Altitudinal Pattern of Pteridophyte in Arghakhanchi district, West Nepal

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Abstract

Pteridophyte species richness pattern was carried out in Arghakhanchi district, West Nepal during October-November, 2018 and 2019. Main objectives of this study were to document the floristic composition of pteridophyte and to access the species richness pattern along altitude, temperature, rainfall and area per 100 m contour elevation. The pteridophyte species were recorded and collected after utilizing systematic random sampling strategies in each forest types into 10 x 10 m^2 area each 100 m altitudinal band from the bottom to the top of the mountain (240-2300 m asl). Herbarium of each collected pteridophyte sample present inside plots and along the track was identified with the help of the published literature and deposited in the TUTH. The pteridophyte species richness was plotted against altitude, interpolated temperature, rainfall and area per 100 m contour elevation through application of the Generalized Linear Model (GLM). The species environment relation was observed by application of CCA. A total of 75 pteridophyte species belonging to 18 families and 36 genera were reported among which Pteridaceae with 5 genera and 21 species was the richest family and *Thelypteris* with 9 species was the richest genera. Among those species 39 species were terrestrial followed by 12 species of lithophytes and 11 epiphytes. The pteridophyte richness showed statistically significant unimodal relationship with altitude and temperature ($R^2 = 0.95$ and $p < 0.001$).Most of the fern species were present at moist places of *Schima-Castonopsis-Quercus* forest above than 1500 m.

Keywords: Contour, Elevation, Habitat, Pteridaceae, Species richness,Unimodal

Introduction

Pteridophyte is a beautiful gift of nature which provides magnificent beauties without flowers. They form an attractive component of the vegetation of hills and forests (Gurung, 1991). They live in habitats from the tropics to polar latitudes unlike seeded plants; they reproduce by minute spores (Moran, 2004). The popular Nepalese local slogan "Unyu phulnu ra dhunga rasaunu ekai ho" says that ferns have neither seeds nor flowers but can reproduce offspring. They complete their life-cycle in two generations: sporophyte and gametophyte. Pteridophyte is a unique group of plant with two phases independent life cycle: gametophyte and sporophyte.

Pteridophytes are the earliest vascular plants originated during the Silurian period (400 million years ago) of Paleozoic Era and formed the dominant during Devonian to Permian period (Khare, 1996). They are the most diverse group and the oldest lineage of vascular plant and the second most species after angiosperms with an estimate of 12,000 species in the world (Vidyashree, 2018). Most of them are abundantly found in humid and shady forests area. Nowadays, pteridophyte found grows in different ecological habits thus classified as epiphyte, lithophytes, terrestrial, tree ferns, climbers and hydrophytes (Gurung 1984; Gurung, 1991; Moran, 2004), but some species occur in more than one habitat. Most of them are annual and some are perennial, but some are climbers, creepers and small tree (*Cyathea spinulosa*). They rarely form pure vegetation but form understory inside the forest. Pteridophyte foliage is highly considered as economically valuable in decoration, food, medicine, biofertilizer, ornamental and reclamation of contaminated soil (Vidyashree, 2018). Being very sensitive to direct sunlight, epiphytic ferns could be used as indicators of forest disturbances (Edward et al., 2003) andhave wide range of habitat preferences (Nagalingum & Cantrill, 2015).

Nepal has a rich and diversified bioresources due to varied topographical and climatic regions. The studies on species richness patterns of Medicinal plants (Acharya et al., 2010), orchids (Acharya et al., 2011), higher plants (Bhattarai & Vetaas, 2003), ferns (Bhattarai et al., 2004), bryophytes (Grau et al., 2007) in Nepal's mountains show unimodal pattern with variation in peak. Many studies in ferns (Bhattarai & Vetaas, 2003; Watkie et al., 2006; Nagalingum & Cantrill , 2015; Jeyalatchayan et al., 2020) showed that unimodal is common pattern of fern species against altitude. In many cases, area accounts the large percentage of variation than altitude (Xiang et al., 2017). The environmental gradient drives pattern of fern species richness on the spatial scale (Watkin et al., 2006). Climate is one of the strongest predictors for diversity of species and their richness, especially for epiphytic species (Zhang et al., 2015).

The Department of Plant Resources (DPR), Nepal (2002) reported 534 species of pteridophyte species in Nepal. Fraser-Jenkins et al. (2015) reported 580 species of pteridophyte in Nepal. These reports only generalized the number of pteridophyte species present in the whole country after enumeration. No direct ecological study has been taken yet so far focusing on the definite landscape. Arghakhanchi, one of the middle mountains in Nepal, lies in the borderline between tropical and subtropical ecological zones as well as beginning of west Nepal has been considered as important place to this study. The main objectives of this paper were documentation of pteridophyte species present in Arghakhanchi district and find out the pteridophyte species richness pattern along altitude temperature, rainfall and area per 100 m contour elevation.

Materials and Methods

Physiography and vegetation of the study area

Arghakhanchi, one of beautiful hilly districts, is located in providence no. 5, West Nepal. Arghakhanchi occupies an area of 1193 km^2 and extended between 27º45' to 28º06' N and 80º45' to 83º23' E (Figure 1). The population of this district was 197,632 (Central Bureau of Statistics [CBS], 2012). Other neighboring districts are Palpa in the east, Gulmi in the north, Kapilbastu and Rupandehi in the south and Pyuthan and Dang are in the west. About 68% land of this whole district lies within the Mahabharata range and remaining are in the Siwalik Hills. The elevation of this district ranges from 240 to 2515 masl (Alternative energy promotion center, [AEPC], 2016).

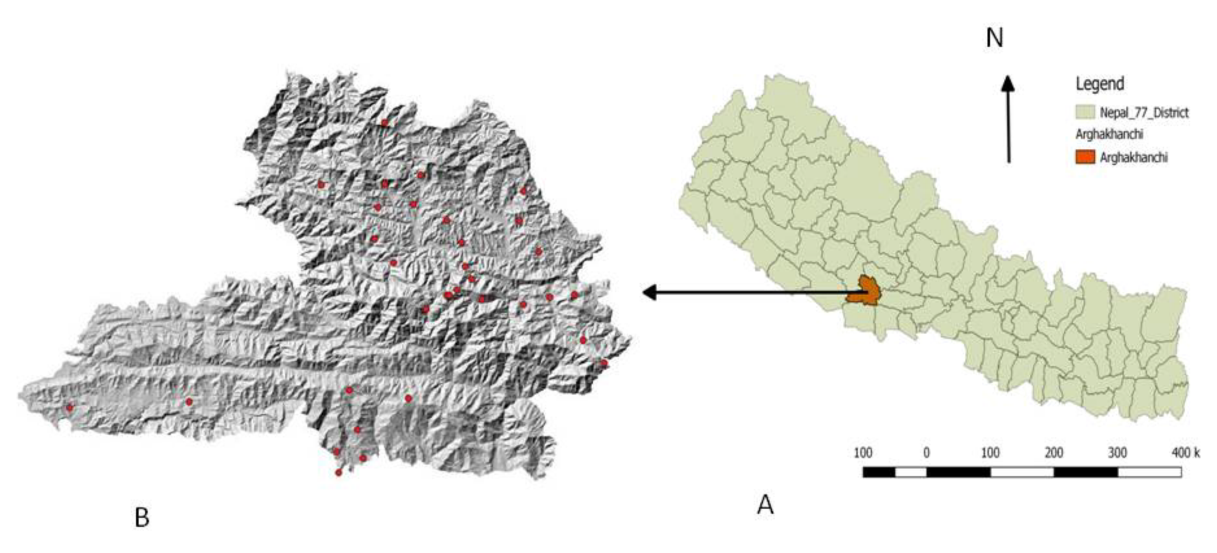

Figure 1: A. Arghakhanchi district in Nepal, B. Botanically explored sites (Drawn by using QGIS)

Physiographically, this district has four zones: lower tropical (less than 300 m asl) which covers 0.2%, upper tropical (300-1000 m asl) coves 51%, subtropical (1000-2000 m asl) which covers 49% and temperate zone (2000-3000 m asl) of 0.2% (CBS, 2012).The maximum and minimum average mean temperatures ranged between 25-27°C and 5-7°C respectively between May-July and January (Department of Hydrology and Meteorology [DHM, 2017). The average annual rainfall of this district remains around 1750 mm (CBS, 2012). Arghakhanchi district lies in the moderate temperate climatic zone of the country.

In Arghakhanchi, about 40 % of the total land is covered by the forest. Lowland (below 500 m asl) towards south consists of lower tropical *Shorea robusta* forest. Churia Sal forest lies between 500-1000 m asl and Inner hill Sal forest (up to 900 m). Northern slope of this district lies in the Mahabharat range (1000-1500 m) with the broad leaved forest intermixed with *Pinus* species. Between 1500-2000 masl, *Rhododendron arboreum, Schima wallichii, Pinus roxburghii, Myrica esculenta,* containing forest are present. The uppermost region (above 2000 m) in this district bear *Rhododendron-Quercus-Maesa* mixed forest with bushes (Panthi & Chaudhary, 2002).

Sampling design and primary data collection

The Arghakhanchi district is mainly occupied by two landscapes(Narapani-Masina landscape, 200-2200 m and Malarani-Gokhunga landscape, 700-2300 m) which are extended from East to West. The overall altitude range of this district was divided equally by 100 elevation band. The field was visited and sampled twice in the post-monsoon (October and November) of 2018 and 2019. 3-4 Sampling plot of 10 x 10 m^2 was placed at each altitudinal band of both aspects (north and south) focusing at the forest type. The distance between two sample plots varied from 100 to 150 m distance.

All pteridophyte species enrooted inside each plot was recorded and one sample of each species was collected. Photograph of each pteridophyte sample was taken. The coordinate of each plot location was also measured through GPS (*eTrex*). The pteridophyte species present outside the plots and along the track were also collected and their habitats and coordinate were also noted.

Herbarium of each properly dried and specimens were prepared in the laboratory. GPS data and other micro-ecological characters were also recorded to each herbarium specimen. All herbarium specimens were identified with the help of relevant taxonomic literature such as Gurung, 1984 & 1991; Fraser-Jenkins et al., 2015; Rajbhandary, 2016; Fraser-Jenkins & Kandel, 2019. Some species were also identified with the help of consulting experts and comparing with specimens deposited at National Herbarium and Plant Laboratories (KATH) and Tribhuvan University Central Herbarium (TUCH). All these identified herbarium were submitted in the TUCH. After identification, the altitudinal range of each species was determined on the basis of their maximum and minimum altitude.

Altitudinal area and climatic variables calculation

Species numbers tend to increase as the area increase (Rahbek, 1997), but area per 100 contour elevation does not contain equal areas due to complex pyramidal and topography of Himalayas along the elevational gradient. So, the area occupied per 100 m contour elevation of Arghakhanchi district was calculated by using Digital Elevational Model (DEM) in QGIS. Similarly, physiographic and climatic information obtained from the Department of Hydrology and Meteorology and their periodical publications such as Ministry of Agriculture and Co-operatives [MoAC], (2011),DHM (2017).The climatic variables used in this study are mean annual average temperature (AMT) and mean annual Total rainfall (MAR). The climatic records 20 years (1994-2013) of 11 stations of Arghakhanchi and surrounding districts were collected. The temperature was interpolated in 100 m counter elevation by linear regression ($r^2 = 0.99$; $p \leq 0.001$) at lapse rate of 0.5°C/100 m for mean annual temperature (AMT). Rainfall is not a simple linear function of elevation, and therefore a cubic smooth spline in Generalized Additive Model (Hastie & Tibshirami, 1990) was used with 4 degrees of freedom to estimate total annual rainfall in each 100 m counter elevation.

Statistical analysis

The patterns related to pteridophyte species as response and their altitudes, area per 100 m contour elevation, temperature and rainfall as predictor variables were analyzed after underlying the principal of Generalized Linear Model (GLM) in R 3.6.2 (R Core Team, 2019). The quasi-poisson family of error distribution was applied to remove over dispersion as Baniya et al. (2010). The assumption of normal distribution of error was conformed after Q-Q diagnostic plots plotted against residuals. The change in deviance follows the F-distribution. Canonical Correspondence Analysis (CCA) used to analyze species environmental composition (Kent & Carmel, 2011).

Results and Discussion

Pteridophyte diversity in Arghakhanchi district

A total of 75 species of pteridophytes belonging to 18 families and 36 genera were found in Arghakhanchi district. The largest families were: Pteridaceae (6 genera with 22 species), Polypodiaceae (8 genera with 11 species) (Figure 2).

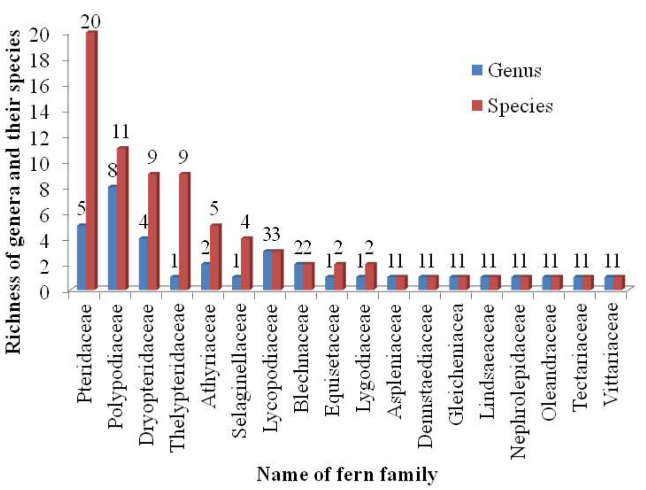

Figure 2: Richness of family wise genera and species of fern

There were 8 monogeneric (having single genus and single species) families: Aspleniaceae (*Asplenium ensiforme,)* Dennstaediaceae (*Pteridium revolutum*), Gleicheniaceae (*Dicranopteris lanigera),* Lindsaeaceae (*Odontosoria chinensis*), Nephrolepidaceae (*Nephrolepis cordifolia*), Oleandraceae (*Oleandra wallichii*), Tectariaceae (*Tectaria gemmifera*), Vittariaceae (*Vittaria linearifolia* Ching) (Table 1). The largest species bearing genera were: *Thelypteris* (9 species), *Aleuritopteris* (6 species) and *Pteris* (5 species) (Table 1).

Pteridophyte distribution according to habitats

Pteridophyte of Arghakhanchi was found distributed into three broad habitats: terrestrial, epiphytes and lithophytes. This study found 39 terrestrial species followed 12 species of lithophytes and 11 species of epiphytes (Figure 3). The epiphytic species *Asplenium ensiforme*, *Lepisorus loriformis*, *Pyrrosia flocculosa*, *Pyrrosia porosa* were found above than 1500 m asl. The species of *Adiantum*, *Aleuritopteris Pteris, Thelypteris* were distributed at all types of forest from low to high altitude (Table 1). 47 species (63%) were present in moist places of *Schima-Castonopsis-Quercus* forests.

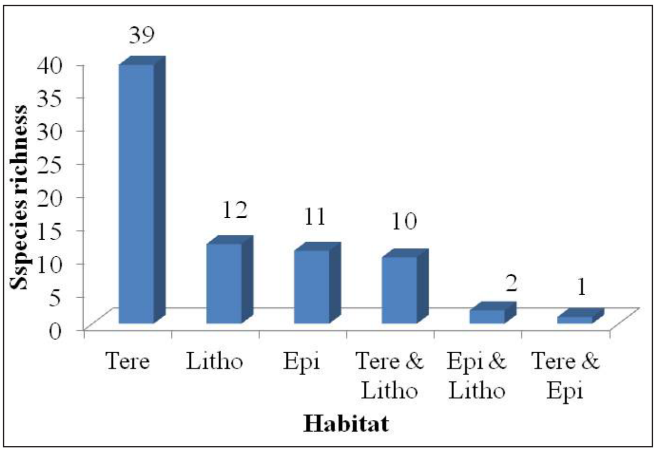

Figure 3: Pteridophyte species richness on the basis of habitat (Tere-Terestrial, Litho-Lithophyte & Epi-Epiphytes)

Species richness pattern and species environment relation

The pteridophyte species richness showed statistically highly significant unimodal richness pattern against both altitude and area per 100 m contour elevation in Arghakhanchi district (Figure 4 A and B**)**. The pteridophyte species richness was found maximum spp. 66 at 1300 m asl and then declining ($R^2 = 0.95$ & $p < 0.001$, Figure 4A). Similarly, species richness was found statistically unimodal pattern with area per 100 m asl contour elevation with the peak at 800 m (maximum species = 46&$R^2 = 0.28$; Figure 3B). The species richness also showed the unimodal structure against temperature ($R = 0.95, p < 0.001$) and rainfall ($R^2 = 0.42; p < 0.001$).

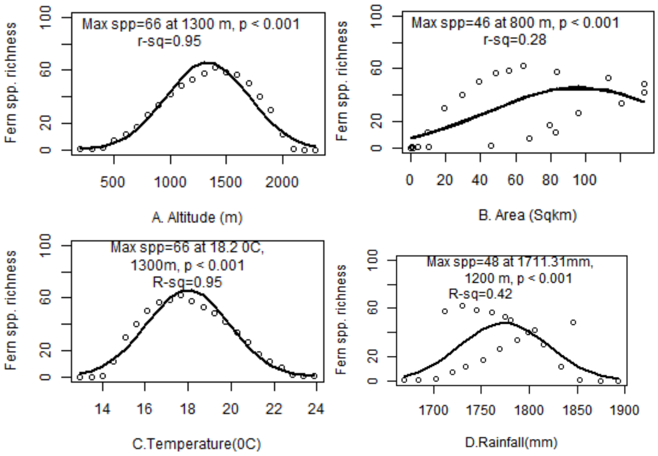

Figure 4: Scatter plots of the relationships between Pteridophyte species richness and (A) altitude & (B) area per 100 m contour elevation and (C) temperature & (D) rainfall which shows the second order polynomial fitting curves generated using *GLM* model.

The temperature and area showed the negative relation with altitude (Figure 4), but rainfall did not show any particular relation. The *Dicranopteris lanigera*, *Thelypteris glanduligera*, *Athyrium pectinatum*, *Polystichum discretum*, *Equisetum ramosissimum*, *Selaginella subdiaphana*, *Adiantum philippense*, *Lygodium japonicum* etc. were present dominant condition in Sal forest at low elevation. The species *Adiantum venustum*, *Asplenium ensiforme*, *Dryopteris chrysocoma*, *Lepisorus loriformis*, *Lepisorus scolopendrium*, *Polypodiodes lachnopus*, *Onychium lucidum*, *Pteris wallichiana*, *Vittaria linearifolia*, *Pyrrosia flocculosa*, *Woodwardia unigemmata* etc were present at moist places of *Schima-Castonopsi*, *Schima-Querscus*and *Schima-Diploknema* forests at high altitude (Figure 5 & Table 1).

The result shows that Arghakhanchi is rich in pteridophyte diversity due to presence of about 13% of total pteridophyte species of Nepal. Pteridaceae is the richest family and Polypodiceae lies in second position. Polypodiaceae (polypod ferns) with 4,080 species is the largest family of ferns in world (State of the World Plant [SOTWP], 2017). There are of 8 monogeneric families and 23 genera consist of single species. This fact also indicates the variation in fern diversity.

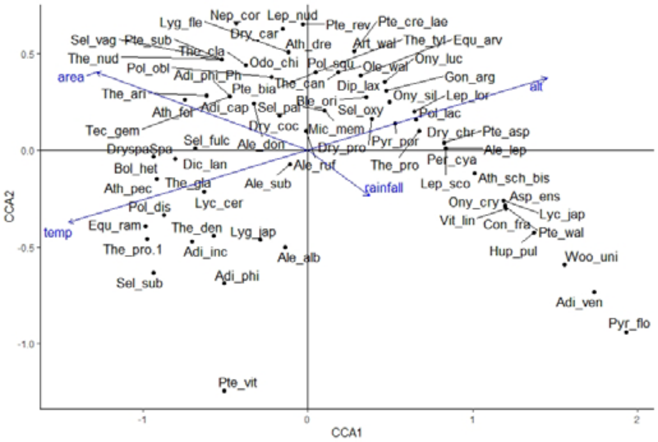

Figure 5: CCA biplot showing relationship among species and environment variables

Most of the fern species are terrestrial which are followed by lithophytes and epiphytes. The Presence of more terrestrial species indicates the favorable condition on land for fern diversity in this area. The species *Oleandra wallichii*, *Drynaria propinqua*, *Lepisorus loriformis*, *Lepisorus nudus* etc. are inhabiting on the bark of perennial trees as *Schima-Castanopsis*, *Castonopsis-Quercus forest of* areas above than 1500 m asl. The presence of more epiphytic specieson higher altitude possibly occurs due to increasing environmental humidity (Acebey et al., 2017). Shrestha & Rajbhandary (2019) also found the most of the epiphytic species on barks of *Quercus*, *Acer* & *Betula* species. The epiphytic ferns cannot survive as the forest become more and more open (Edward et al., 2003), or they lie mainly on ecologically undisturbed forest. Presence of epiphytic fern indicates that some forest of this area provides suitable place for epiphytic ferns.

The fern species shows dome shaped pattern against altitude, area and interpolated temperature and rainfall. Lili et al. (2014) found the hump shaped pattern of fern against altitude, area, mean annual temperature and mean annual precipitation. Bhattarai et al. (2004) also reported unimodal pattern of fern species against altitude in central Nepal with maximum species at 2000 m. The richness of terrestrial fern species exposes the mid elevation maximum (Watkin et al., 2006).The species richness plotted the peak value at 1300 m against altitudeand sharply decreased onwards in this study. This decreased altitude of highest modeled species richness than Bhattarai et al. (2004) may be the matter of scale and hard boundary effect due to low altitudinal range of species or narrow distribution. The random placement of range of species increases the overlap of species towards middle of geographical domain and results hump shaped (Colwell & Lees, 2000). This shows that species richness generally increases with increase of elevation and decrease of temperature and fitness of unimodal pattern of fern species looks stronger with altitude and temperature ($R^2 = 0.95$) than area and rainfall.

Rainfall does not show clear relation with temperature and altitude, but temperature showed opposite relation with altitude. However, these parameters showed effect in distribution pattern of species. No single variables can explain for distribution of plants (McCain & Grytnes, 2010). Altitude determines the climatic condition of any place and is main controlling factor of altitudinal species richness than others Li & Feng, 2015.The actual mechanism controlling the patterns lies in a combination of factors related to biology, the environment and geometric constrains on geographical range (Watkins et al., 2006).The area size can also significantly affect relationship between species richness and elevation and covers the effects of other predictors (Xiang & Hua-yong, 2017). Generally, area decreases with the increase of altitude in the Himalaya region.The increasing area per elevation band up to mid altitudinal range may be played main role to develop the unimodal pattern of species richness.

According to Acebey et al. (2017) the understory is a very important habitat for epiphytic ferns and others depending on the elevational zone. The different microhabitats in the forest understory determine the high diversity of epiphytes (Kromeret al., 2007).The number of epiphytes found in dense and moist forests is comparatively higher than those found on trees in open and dry areas (Rajbhandary, 2016). The species like *Adiantum venustum, Asplenium ensiforme, Dryopteris chrysocoma, Lepisorus loriformis, Lepisorus scolopendrium, Polypodiodes lachnopus, Onychium lucidum, Woodwardia unigemmata* etc. are restricted at Schima-Castonopsis- Quercus forest above than 1500m which covers about 25% of total species.

The study shows that most of the fern species are moist loving and present at north aspect of hills.

Conclusion

On the floristic study of Pteridophyte, 75 species belonging to 18 families and 36 genera were found in Arghakhanchi**.** Peridaceae consisting of 5 genera and 21 species was found the richest family. Most of the species (39) were located as terrestrial. The species richness showed the statistically significant unimodal pattern against altitude and temperature. Most of the fern species were present at moist places of *Schima-Castonopsis-Quercus* forest above than 1500 m. The further detail systematic study of plants including pteridophyte and their ecological status in this district is necessary.

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Table 1: Name list of Pteridophyte found in Arghakhanchi district

S.N.	Family	Name of species	Habitat	Altitude Range	*Location (® Type of Forest, Altitude)
1	Aspleniaceae	*Asplenium ensiforme* Wall. ex Hook. & Grev.	Epi	1600-1900	Ml(SQ.1610),Go(CS,1890)
2	Athyriaceae	*Athyrium drepanopterum* (Kunze) A. Braun ex Milde	Tere	1000-1700	Bh(SP,1520), Da(PS,1010), Ka(SC,1680)
3	Athyriaceae	*Athyrium foliolosum* T.Moore ex R.Sim	Tere	800-1400	Bh(SP,820),Sa(SP,1400)
4	Athyriaceae	*Athyrium pectinatum* (Wall ex Mett.) T. Moore	Tere	600-1300	Ba(S,620),Th(S,1320);Ra(S,1100)
5	Athyriaceae	*Athyrium schimperi* Moug.ex Fee subsp biserrulatum (Christ)	Tere	1500-1900	Se(SC,1915), Dh(SC,1510)
6	Athyriaceae	*Diplazium laxifrons* Rosenst.	Tere	1100-1900	Ml(SQ,1880); Ro(CS,1090)
7	Blechnaceae	*Blechnum orientale* L.	Tere	1100-1700	Dn(SC,1110), Se(SC,1685)
8	Blechnaceae	*Woodwardia unigemmata* (Makino) Nakai	Tere	1700-2000	Ml(SQ,1730;1990)
9	Dennstaediaceae	*Pteridium revolutum* (Blume) Nakai	Tere	1200-1600	Ml(SQ,1610),Sa(CS,1220)
10	Dryopteridaceae	*Bolbitis heteroclita* (C. Presl) Ching	Tere&Litho	800-1200	Hi(S,820), Ra(S,1190)
11	Dryopteridaceae	*Dryopteris carolihopei* Frasser-Jenk	Tere	1100-1600	La(CS,1080), Gl(CS,1380), Dn(SC,1580)
12	Dryopteridaceae	*Dryopteris chrysocoma* (Christ) C. Chr.	Tere	1300-2000	Se(SC,1985),Sa(CS,1310)
13	Dryopteridaceae	*Dryopteris cochleata* (D. Don) C. Chr.	Tere&Litho	800-1800	Ny(S,820), Ka(SC,1770)
14	Dryopteridaceae	*Dryopteris sparsa* (D.Don) Kuntze subsp. Sparsa	Tere	700-1400	Sa(SC,1410), Bh(SP,1120),Ra(S,710)
15	Dryopteridaceae	*Peranema cyatheoides* D.Don	Tere	1400-1900	Poudi khola(PS,1425), Ga(SQ,1910)
16	Dryopteridaceae	*Polystichum discretum* (D.Don) Sm	Tere	600-1400	Gl(CS,1390),Do(S,610),
17	Dryopteridaceae	*Polystichum obliquum* (D. Don) T. Moore	Tere	900-1700	Ro(CS,910),Ha(CS,1120), Kh(RS,1690)
18	Dryopteridaceae	*Polystichum squarrosum* (D. Don) Fée	Tere&Litho	1000-1800	Kh(RS,1780),Sa(SC,1340),Bh(SP,1020)
19	Equisetaceae	*Equisetum arvense* L.	Tere	1200-1800	Na(SQ,1810), Po(PS,1225)
20	Equisetaceae	*Equisetum ramosissimum* Desf.	Tere	700-1200	Kc(W,885), Bh(SP,1120), Du(W,720)
21	Gleicheniacea	*Dicranopteris lanigera* Fraser-Jenk.	Tere	700-1400	Th(S,1380), Pk(810),Si(690)
22	Lindsaeaceae	*Odontosoria chinensis* (L.) J. Sm.	Tere	900-1600	Bh(SP,930),Da(SP,1595)
23	Lycopodiaceae	*Huperzia pulcherrima* (Wall. ex Hook. & Grev.) T. Sen & U. Sen	Epi	1600-2000	Kh(RS,1630), Ms(SC,2020)
24	Lycopodiaceae	*Lycopodiella cernua* (L.) Pic. Serm.	Tere& Lit	600-1600	Si(SC,625), Na(PS,1582)
25	Lycopodiaceae	*Lycopodium japonicum* Thunb.	Tere	1600-1850	Ka(SC,1590; 1780)
26	Lygodiaceae	*Lygodium flexuosum* (L.) Sw.	Tere	1000-1700	Am(S,960),Bh(SP,1650)
27	Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.	Tere& Lit	500-1900	Do(S,520), Am(S,950),Wa(S,1340),Ag(PS,1890)
28	Nephrolepidaceae	*Nephrolepis cordifolia* (L.) C. Presl	Tere	1000-1500	Ny(SC,1115), Ma(SC,M,1300),Gl(CS,1480)
29	Oleandraceae	*Oleandra wallichii* (Hook.) C. Presl	Epi	1100-1800	Se(SC,1785), Gl(CS,1120), Ml(SQ,1685)
30	Polypodiaceae	*Arthromeris wallichiana* (Spreng.)Ching	Epi	1300-1700	Ma(SS,1310), Ka(SC,1680)
31	Polypodiaceae	*Drynaria propinqua* (Wall. ex Mett.) Bedd.	Epi	1000-2000	Se(SC,1985), De(SC,1550), Dd(CS,1020)
32	Polypodiaceae	*Goniophlebium argutum* (Wall. ex Hook.) J. Sm. ex Hook.	Epi	1400-1700	Ja(P,1420), Ml(SQ,1710)
33	Polypodiaceae	*Lepisorus loriformis* (Wall. ex Mett.) Ching	Epi	1300-1900	Bh(SP,1290), Al(SC,1520),Na(SC,1880)
34	Polypodiaceae	*Lepisorus nudus* (Hook.) Ching	Epi & Lit	1200-1600	Dn(SC,1800), Dh(SC,1620),Da(SP,1220)
35	Polypodiaceae	*Lepisorus scolopendrium* Mehra& Bir	Epi	1400-1900	Bh(SP,1380),Se(SC,1910)
36	Polypodiaceae	*Microsorum membranaceum* (D. Don) Ching	Tere& Epi	900-1900	Rosa(CS,910),Se(SC,1890), Gl(CS,1498)
38	Polypodiaceae	*Pyrrosia flocculosa* (D. Don) Ching	Epi	1600-2000	Ml(SQ,1610; 2010)
39	Polypodiaceae	*Pyrrosia porosa* (C. Presl) Hovenkamp	Epi	1100-1900	Ka(SC,1780), Dd(CS,1120)
40	Polypodiaceae	*Selliguea oxyloba* (Wall. ex Kunze) Fraser-Jenk.	Epi	1000-2000	Ms(B,1950); Na(PS,1620); Da(CS,980)
41	Pteridaceae	*Adiantum capillus* veneris L.	Lit	800-1700	Bh(SP,780), Da(SC,1680)

42	Pteridaceae	*Adiantum incisum* Forssk.	Lit	500-1600	Am(S,1050), Ra(S,520), Na(SC,1610)
43	Pteridaceae	*Adiantum philippense* L.	Lit	400-1800	Do(S,390),Am(S,990),Na(SQ,1790), Ha(CS,1220)
44	Pteridaceae	*Adiantum philippense* L.subsp. philippense	Lit	800-1600	Bh(SP,810), Na(SC,1580)
45	Pteridaceae	*Adiantum venustum* D.Don	Lit	1700-2100	Ml(SQ,1710;2080)
46	Pteridaceae	*Aleuritopteris albomarginata* C.B. Clarke	Lit	500-2000	Do(S,480);Ar(PS,1770), Gl(CS,1190),Go(SQ,1970)
47	Pteridaceae	*Aleuritopteris doniana* S.K. Wu	Lit	800-1700	La(CS,815), Sa(SC,1450),Di(PS,1705)
48	Pteridaceae	*Aleuritopteris leptolepis* (Fraser-Jenk.) Fraser-Jenk.	Lit	1400-1900	Se(SC,1880), Gl(CS,1415)
49	Pteridaceae	*Aleuritopteris rufa* (D. Don) Ching	Lit	800-1900	Se(SC,1880), Ar(PS,1710),La(CS,790)
50	Pteridaceae	*Aleuritopteris subdimorpha* (C.B. Clarke & Baker) Fraser-Jenk.	Lit	700-1900	Se(SC,1890), Gl(CS,1415), Ha(CS,900),Ba(S,710)
51	Pteridaceae	*Coniogramme fraxinea* (D.Don) Fee ex Diels	Tere	1700-1900	Ml(SQ,1690;1910)
52	Pteridaceae	*Onychium cryptogrammoides* Christ	Tere	1500-2000	Se(SQ,1920), Da(PS,1520)
53	Pteridaceae	*Onychium lucidum* (D. Don) Spreng.	Tere	1300-1800	Se(SC,1780),De(SC,1305)
54	Pteridaceae	*Onychium siliculosum* (Desv.) C. Chr.	Tere& Lit	1200-1900	Bh(S,885), Ml(SQ,1780), Se(SC,1880)
55	Pteridaceae	*Pteris aspericaulis* Wall. ex J. Agardh	Tere	1300-2000	Ms(B,2020), Na(SC,1710) , Bh(SP,1320)
56	Pteridaceae	*Pteris biaurita* L.	Tere& Lit	1000-1800	Se(SC,1780),Am(S,980)
57	Pteridaceae	*Pteris cretica* var. laeta (Wall. ex Ettingsh.) C. Chr. & Tardieu	Tere	1300-1700	Bh(SP,1320),Na(SC,1680)
58	Pteridaceae	*Pteris subquinata* Wall. ex J. Agardh	Tere	900-1500	Th(S,1240), Pk(CS,840), Sa(SC,1480)
59	Pteridaceae	*Pteris vittata* L.	Tere& Lit	200-1900	Se(SQ,1875), Gl(CS,1320), Am(S,1070), Do(S,230)
60	Pteridaceae	*Pteris wallichiana* J. Agardh	Tere	1400-2100	Kh(SQ,2065), Pn(CS,1400)
61	Selaginellaceae	*Selaginella fulcrata* (Buch.-Ham. Ex D.Don) Spring	Tere	700-1500	Kc(W,770),Bh(SC,1205), Gl(CS,1490)
62	Selaginellaceae	*Selaginella pallida* (Hook. &Grev.) Spring	Tere	900-1900	Ro(CS,910),Se(SQ,1880), Gl(CS,1380)
63	Selaginellaceae	*Selaginella subdiaphana* (Wall. Ex Hook & Grev.) Spring	Tere	500-1400	Do(S,505),Bh(SP,1160), Gl(CS,1410)
64	Selaginellaceae	*Selaginella vaginata*	Tere& Lit	900-1500	La(CS,910),Gl(CS,1480)
65	Tectariaceae	*Tectaria gemmifera* (Fée) Alston	Tere& Lit	800-1600	Bh(S,810),Pn(CS,1350), Gl(SC,1580)
66	Thelypteridaceae	*Thelypteris arida* (D.Don) C.V.Mortum	Tere	800-1500	Du(W,780),Gl(CS,1470), Bh(SP,1120)
67	Thelypteridaceae	*Thelypteris cana* (J.Sm.) Ching	Tere	1100-1800	Pa(SS,1325),Th(SS,1120), Ka(SC,1810)
68	Thelypteridaceae	*Thelypteris clarkei* (Bedd.) C.F.Reed	Tere	900-1600	Ra(S,910), Ja(PS,1220), Ml(SC,1610)
69	Thelypteridaceae	*Thelypteris dentata* (Forssk.) E.P. St. John	Tere	500-1700	Do(S,520),Th (SS,1250), Da(SC,1670)
70	Thelypteridaceae	*Thelypteris glanduligera* (Kunze) Ching	Tere	600-1600	Si(SC,650), Sa(SC,1420),Gl(SC,1590)
71	Thelypteridaceae	*Thelypteris nudata* (Roxb.) C.V. Morton	Tere	900-1500	Bh (S,920),De(PS,1260), De(SC,1510)
72	Thelypteridaceae	*Thelypteris procera* (D.Don) Fraser-Jenk	Tere	1200-1900	Se(SQ,1910), Bh(SP,1220)
73	Thelypteridaceae	*Thelypteris prolifera* (Retz.) C.F.Reed	Tere	600-1300	Do(S,580), ,Th(S,1310)
74	Thelypteridaceae	*Thelypteris tylodes* (Kunze) Ching	Tere	1000-1800	Se(SC,1780), Pn (CS,1020)
75	Vittariaceae	*Vittaria linearifolia* Ching	Lit	1300-2000	Dh(SC,1620),Ms(RS,1980), Pn(SP,1290)

Note: Ag-Argha, Al-Alamnagar, Am-Amadanda, Ar-Arichour, Ba-Baseri, Bh-Bhuwandanda, Da-Dahakhola, Dd-Daduwa, Dh-Dhakaband, Di-Diverna, Dn-Dhanchour, Do-Dohote, Du-Durghaphat, Ga-Gargare, Gl-Goldhung, Go-Gokhunga,Ha-Halde, Hi-Hilekhola, Ja-Jalkanda, Ka-Kalikathi, Kc-Khanchikhola, Kh-Khanchi, la-Lamdanda, Ma-Maidan, Ml-Malarani, Ms-Masina, Na-Narapani, Ny-Nayagaun, Pa-Patauti, Pn-Panku, Pk-Pokhadanda, Po-Poudikhola, Ra-Rajiya, Ro-Rosa, Sa-Sanodeva, Se-Sengleng, Si-Sitkhola, Th-Thada & Wa-Wangla

Types of forest: S= Sal, SC=Schima-Castonopsis, SQ= Schima-Quercus; SP=Sal-Pinus; SS=Sal-Schima; P=Pinus; CS=Chiuri-Sal; PS=Pinus-Schima, RS=Rhododendron-Schima; W=Wetland; B=Bushes

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Diversity Patterns of Vascular Plants at Varied Elevations in Arghakhanchi, West Nepal

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Abstract

The genuine image of biodiversity, as well as their germplasm, is visualized by the turnover of species rather than their similarities in each location. The major goal of this study was to determine the β-diversity pattern of vascular plants growing at 100 m contour elevations and to explore its association with α-diversity and elevation. Primary data were gathered utilizing 4-6 10 x 10 m^2 quadrats at 100 m contour elevation, on both the south and north sides, in Arghakhanchi district, west Nepal. Beta diversity represents the change in diversity of species between two communities and is measured by two different matrices: species turnover and similarity. Between two adjacent elevational bands, the species turnover was calculated using the Bray-Curtis dissimilarity index and similarity was assessed using the Jaccard index technique in the Vegan package for R version 4.03. The species richness (α-diversity) and β-diversity indices (Bray-Curtis dissimilarity index and Jaccard similarity index) were regressed by generalized linear model (GLM) method with elevation. The species richness and Jaccard similarity index suggests statistically significant unimodal structure with elevation; however, Bray-Curtis dissimilarity index suggests statistically significant but reverse unimodal pattern. As a result, rather than species turnover, the presence of more related species usually creates the peak area of a unimodal pattern of alpha diversity. The geographical scale of biodiversity loss or its effective preservation by human activities is revealed by beta-diversity. Any region with high beta diversity suggests a wide variety of species, which aids in the administration of conservation programs.

Keywords: α-diversity, Bray-Curtis method, Jaccard similarity index, Similarity index

Introduction

Space and time bring the drastic variation in distribution of biodiversity as well as their ecological processes. The totality of all biotic variety, from the level of genes to ecosystems, is known as biodiversity, and it is frequently employed as a gauge of the health of biological systems. Current biodiversity is being molded by ecological and evolutionary processes that are being revealed through phylogenetic and temporal investigations. (Yadav & Mishra, 2013). It will serve as the biosphere's foundation for many generations to come in addition to the present. The term "biodiversity" refers to the quantity, variety, and variability of living things within a region or an ecosystem (Heywood & Watson, 1995). The biodiversity can be measured in the form of functional categories (Ecosystem, species and genetic diversity) and theoretical categories (alpha, beta and gamma diversities) (Whittaker, 1972).

Alpha diversity is the species richness present within each forest or each site or each plot. Generally, alpha diversity or species richness is used to show relationship against elevation, latitude, climates, time etc. and patterns vary other environmental conditions. The latitudinal decline of diversity is a universal phenomenon (Hillebrand, 2004). It is frequently asserted that the elevational gradient mirrors the latitudinal gradient and species richness is expected to monotonically decline (i.e. as a result of decreased temperature and subsequent fall in productivity) (Rahbek, 1995). But, the most observed pattern is hump shaped in altitudinal zonation of biodiversity in mountains which can be described well by the mid-domain effect (Fischer et al., 2011; Liang et al., 2020). In northern China, trees exhibit a unimodal trend while shrub species exhibit a linear decline versus elevation, indicating that the elevation pattern is growth form specific (Zhang et al., 2016). The curves are positively skewed and the unimodality is most evident in the most of the global elevational diversity (Guo et al., 2013). According to studies of species distribution, roughly 50% exhibit a Gaussian curve in relation to elevation, whereas 25% show a monotonically falling trend and 25% follow neither of these distributions (Nogués-Bravo et al. 2008). The distribution pattern of a species may depend on its distribution range.

The degree of species compositional variation across sample units, or beta diversity, has evolved into a key method for relating the spatial organization of species assemblages to ecological processes (Ricotta, 2017). Beta diversity, represents by the species diversity between any two patches and their communities (Maiti & Maiti, 2011), measures the change in diversity of species from one site to another. A high beta diversity index indicates a low level of similarity (nestedness), while a low beta diversity index shows a high level of similarity. Fontana et al. (2020) showed that species turnover increases with increasing elevational distance along the gradient for the majority of plant and insect groups, but nestedness was reduced in pastured grasslands in the European Alps. In the Northwest Himalaya, India, the contribution of species replacement or the turnover component to the observed dissimilarity was substantially larger than the nestedness component (Wani et al., 2022). The turnover of species and the nestedness function the two elements of beta diversity.

The deep learning of alpha, beta and gamma diversity frameworks offers a potent and adaptable new technique for evaluating biodiversity patterns (Andermann et al., 2022). Alpha diversity and gamma diversity differ in terms of geographical size. Spatial environmental heterogeneity is an important driver of species diversity (Walters & Martiny, 2020). Large-scale biogeographical patterns have been studied extensively over the Himalayan altitudinal gradients, but no discernible pattern has been found. In places of the Himalayas where fragile soil composition, local anthropogenic pressures and climate change are relatively substantial, knowledge of the alpha diversity and diversity patterns along elevation gradients might assist frame for successful conservation plans (Nanda et al., 2021). According to published research, the humped form represents a typical pattern of species richness in relation to elevation. The reason behind the formation of peaks is not properly studied or identified.

Finding out the elevational pattern of alpha diversity, and beta diversity (species turnover and nestedness) in the Arghakhanchi district are the primary objectives of this study. The other goal is to determine the true cause of the generating peak in the species pattern.

Materials and Methods

Location and vegetation of study area

This research was done in the Narapani-Masina and Resunga-Malarani landscapes of the Arghakhanchi district in western Nepal (27°45' to 28°06'N latitude and 80°45' to 83°23'E longitude) (Figure 1). The research area's elevation ranges from 200 m in the tropical zone to above 2200 m in the lower temperate region, and 177,200 people call this district home (Central Bureau of Statistics [CBS], 2021). Arghakhanchi's neighboring districts are Palpa and Rupandehi to the east, Gulmi to the north, Kapilvastu and Rupandehi to the south and Pyuthan and Dang to the west.

This district is divided into four physiographic zones: lower tropical (less than 300 m asl includes 0.2%), higher tropical (300-1000 m asl covers 51%), subtropical (1000-2000 m asl covers 49%) and temperate zone (more than 2000 m asl contains 0.2%) (Barnekow Lillesø et al., 2005). The maximum temperature ranges between 36°-38°C in May and July and minimum temperature ranges from 9°-11°C in January (Department of Hydrology and Meterology [DHM], 2019). There have been significant variations in the amount of rainfall, with the yearly rainfall at Khanchikot station ranging from 678.2 to 2454 mm (DHM, 2020).

The Terai and Siwalik areas (below 1000 m asl) in Arghakhanchi district are covered with tropical forest, including main species: *Shorea robusta, Dalbergia sissoo, Senegalia catechu* and *Adina*

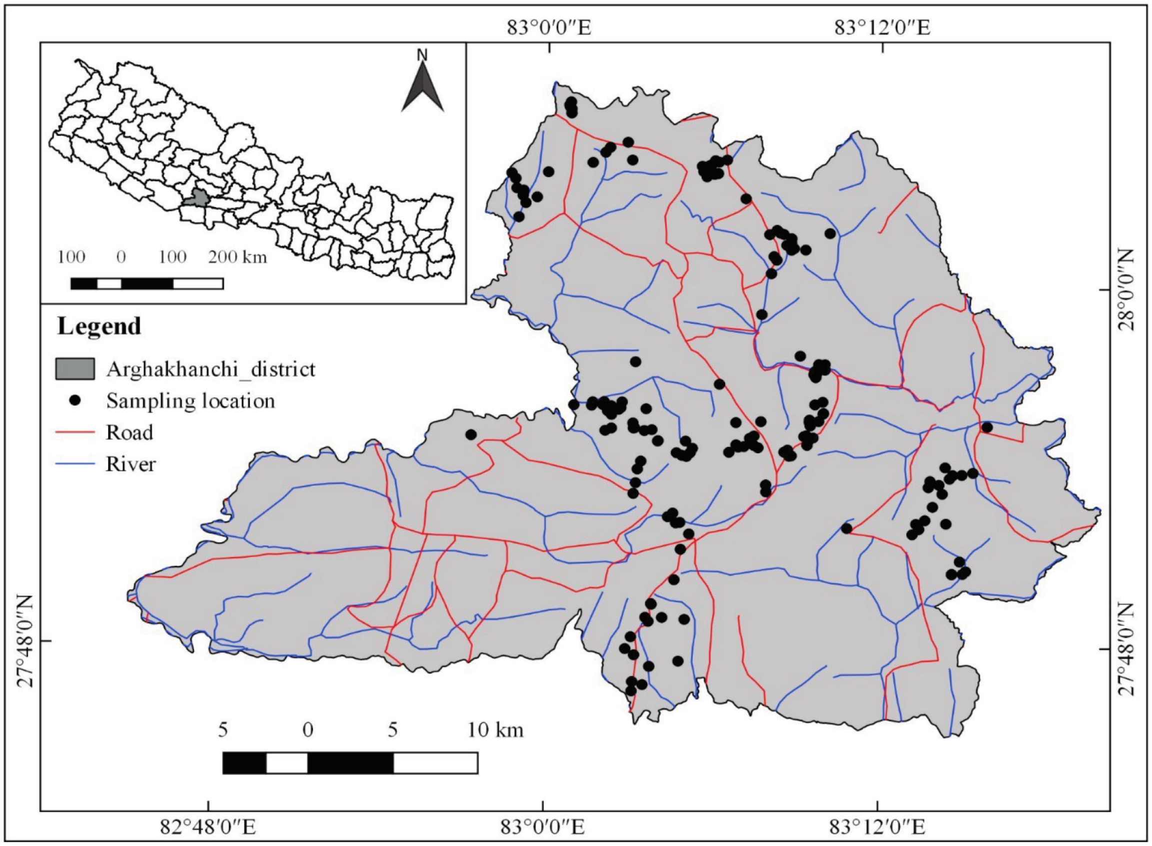


Figure 1: Map of study area with plant sampling sites

cordifolia. The Chure soil in the southern half of the district is more brittle and dry (Singh, 2017). *Shorea robusta* inhabits in the lower belt of the subtropical region (1000-2000 m asl), whereas *Schima walichii, Pinus roxburghii, Diploknema butyracea, Castonopsis indica*, etc. grow in the upper belt. There is more moisture in north-facing landscapes than in south-facing ones. Over 2000 m, *Castonopsis, Quercus*, *Rhododendrons*, etc. cover the majority of this area (Department of Forest Research and Survey [DFRS], 2018).

Study design and data collection

During the first visit, it was decided to divide the entire elevational range of Arghakhanchi district (200-2200 m) into 21 elevation bands each measuring 100 meters. The requisite size of quadrat for sampling of vegetation was determined by following the species area-curve method. A stratified random sample technique was used along the walking trail's horizontal axis at intervals of 100 meters in elevation for the north and south sides of the Narapani-Masina and Resunga-Malarani landscapes. At each 100 m elevation band, 2/2 plots were typically tested on either side of the walking route. In each elevation range, the number of plots was increased to six if various plant types were present. Two plots were set apart by between 100 and 150 meters. The species richness of all sampling plots was recorded in a field note copy.

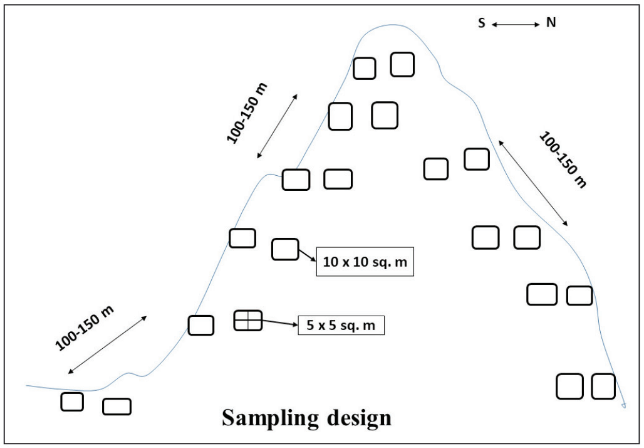


Figure 2: Design for sampling plots in north and south aspect in study site

Later, one voucher specimen of each plant species was collected for further identification. The scientific names of each species and their growth forms (herb, climber, fern, shrub and tree) were identified by comparing with already identified specimens present in National Herbarium and Plant Laboratories (KATH), Godawari, Kathmandu. They are deposited in Tribhuvan University Central Herbarium (TUCH), Central Department of Botany, Kirtipur. The combined species richness of all sampled plots at each 100 m elevational band was considered as species richness of each band.

Statistical analysis of data

The relationship between the abundance of species richness and elevation was expressed using the regression model known as the Generalized Linear Model (GLM) (Hastie & Pregibon, 1993). The error dispersion present in the analysis was removed by use of the Quasi-poisson method.

The species turn over (species dissimilarity) and nestedness (species similarity) are two measures of beta diversity. The species turn over value was calculated by Bray-Curtis Dissimilarity technique (Bray & Curtis, 1957) in R between two adjoining 100 m elevation bands.

The Bray-Curtis Dissimilarity is calculated as:

$$BCij = 1 - (2*Cij)/(Si + Sj)$$

where:

- C_{ij}: The sum of the lesser values for the species found in each site.
- S_i: The total number of specimens counted at site *i*
- S_j: The total number of specimens counted at site *j*

Similar to this, the Jaccard similarity index (Chung, 2018) was estimated by following the formula. In the R Software Package "Jacquard" was used to estimate the Similarity index at same bands.

$$J(A, B) = \frac{!\, A \cap B\, !}{!\, A \cup B\, !}$$

Where,

J = Jaccard similarity index
A = Set 1
B= Set 2

Then, in order to determine the elevational pattern, the Bray-Curtis dissimilarity index value and the Jaccard similarity index were regressed using the GLM technique.

The Post-Hoc Analysis with Tukey's test **(**Bevans, 2020) was used to know the significance differences between alpha diversity (species richness) and elevation as well as beta diversity and elevation for the two aspects of landscapes. The goal of the Tukey's test is to identify the groups in samples that differ from one another. The post hoc test is used to compare means, just as Tukey's, on the basis of the data gathered.

Results and Discussion

Species diversity

A total of 553 species of vascular plants belonging to 115 families and 379 genera was recorded within the study site (Table 1). Among them, 402 species were belonging to dicot and rest was monocot (98 species), ferns and fern-allies (50 species) and gymnosperm (3 species).

Table 1: Total biodiversity of study area

S.N.	Plant group	Families	Genera	Species	Ratio of species (%)
1	Dicots	83	284	402	72.7
2	Monocots	16	69	98	17.7
3	Gymnosperms	1	1	3	0.5
4	Ferns	15	25	50	9.1
	Total	115	379	553	

Relationships of alpha diversity and beta diversity with elevation

The abundance of species is an expression of alpha diversity. There was an alpha diversity of 13-309 per elevation band (Appendix). Similarly, beta diversity is measured using two metrics: species turnover and nestedness. The values for the Bray-Curtis dissimilarity index and the Jaccard similarity

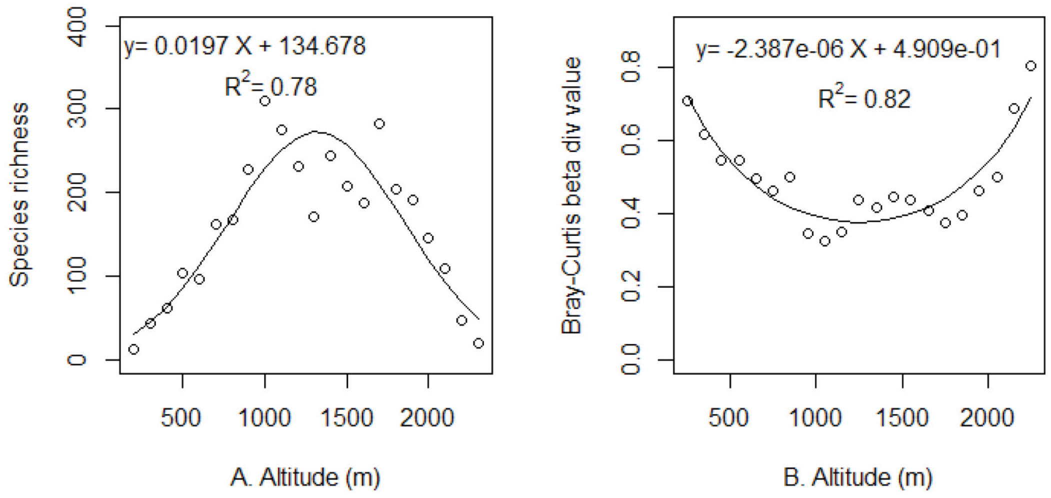


Figure 3: Regression plot applied by GLM method to show relation of species richness, **A.** Alpha diversity with elevation, **B.** Beta diversity against elevation

index were respectively 0.33-0.79 and 0.32-0.70. (Appendix).

Using the GLM regression approach, the alpha diversity, or species richness as well as the beta diversity indices were analyzed to demonstrate the association with elevation. The species richness first increased with height and then began to decline after reaching mid-elevation, even though the elevation increased further, revealing the significant unimodal pattern.($R^2 = 0.78$ & $p < 0.05$, Figure 3A) showing maximum species 264 at 1300 m. However, the elevation started to rise as the beta dissimilarity index value began to fall, indicating a substantial reverse unimodal structure ($R^2 = 0.82$ & $p < 0.05$, Figure 3B) with elevation.

The variation in pattern in the north and south aspects was also shown by the regression analysis of the species richness and Bray-Curtis dissimilarity index. Although the north perspective had a bimodal pattern, the south aspect's alpha diversity revealed a large unimodal structure (Figure 4A). Beta dissimilarity index values at the north and south aspects showed similar differences (Figure 4B) as in aspect wise species richness.

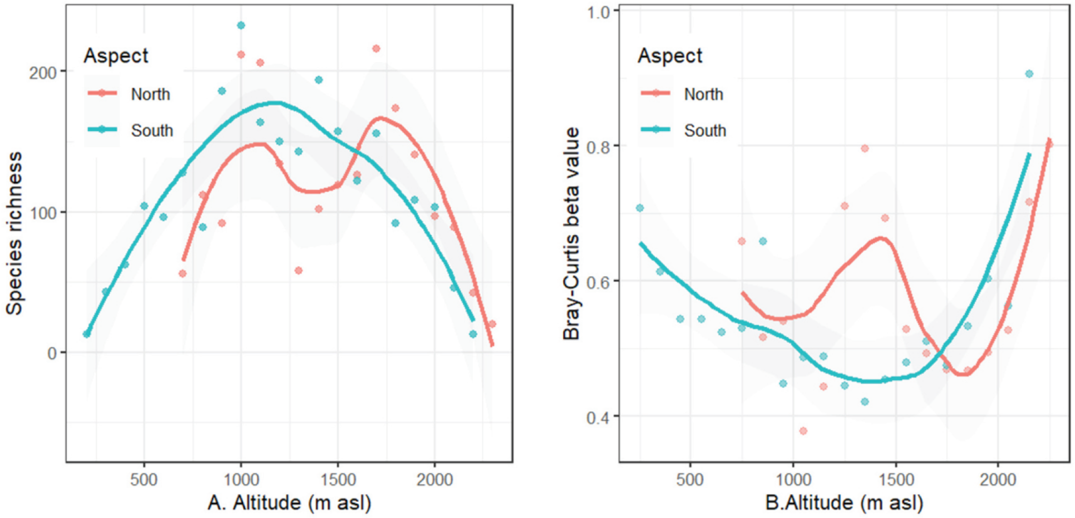


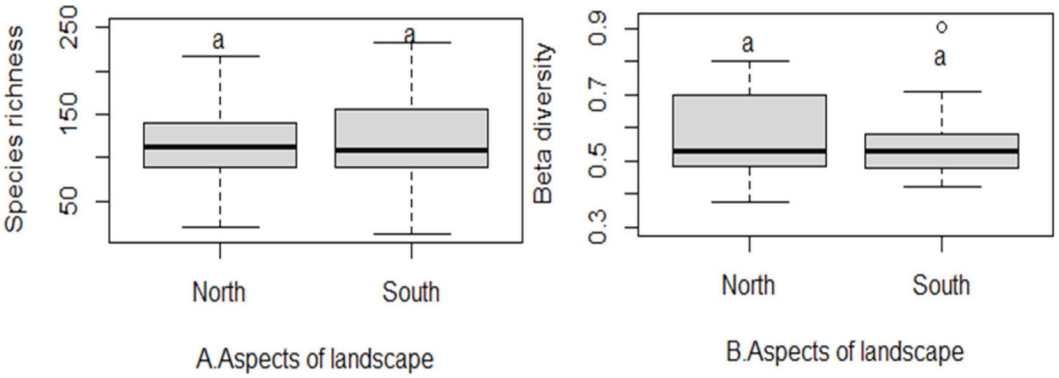
Figure 4: Regression plot applied by GLM method to show relation of, **A.** species richness of two aspects (north and south) with elevation, **B.** Beta diversity of two aspects against elevation

To ascertain if there is a significant difference in the species richness of two features, the Tukey post hoc test is performed. The difference in the Bray-Curtis dissimilarity index value at two aspects was also determined using a similar technique. The test results for both cases revealed that there was no noticeable variation in species richness (Figure 5A) and the beta dissimilarity index (Figure 5B) at two aspects.

Using a generalized linear model, it was attempted to demonstrate how nestedness (species similarity) and species turn over (Bray-Curtis dissimilarity) relate to alpha diversity (Figure 6A and 6B). The statistically significant unimodal pattern with elevation was demonstrated by both the species richness (alpha diversity) and species nestedness (similarity index). However, the dissimilarity index demonstrated a reverse unimodal pattern with elevation that was also statistically significant.

Discussion

Floral diversity and elevational pattern: The fact, that the studied area has 553 species of vascular plants from 115 families and 379 genera shows the diversity of the plant population in Arghakhanchi district. The study area is situated in Nepal's tropical and subtropical zone, which is appeared as place of biodiversity rich. A robust unimodal structure was shown by the regression of species richness (alpha diversity) of the 100 m contour elevation, indicating that mid-elevation sites (1300 m) had a larger species richness than low and high elevation sites.



P < 0.05

Anova by TukeyPost hoc method

Figure 5: Result of Tukey Post hock test of **A.** species richness, **B.** Bray-Curtis dissimilarity index between of two aspects (north and south) ($p < 0.05$)

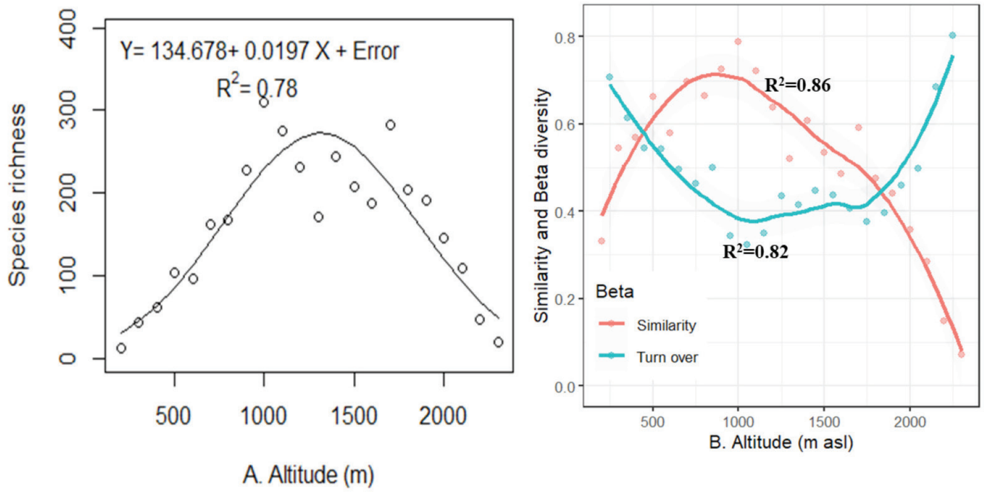


Figure 6: Diagram showing regression result applied by GLM method to show the relation of, **A.** species richness, **B.** beta diversity indices (similarity index and dissimilarity index)

The previous study based on interpolated data (Nepali et al., 2020) had also showed that a statistically significant unimodal pattern ($R^2 = 0.91$; $p < 0.001$) of total vascular species richness with elevation having a maximum richness of 471 species at 1300 m asl. Similarly, individual taxa: gymnosperm, dicot, monocot and pteridophytes species richness also showed a highly significant unimodal altitudinal richness pattern. This study demonstrated that both investigations using interpolated and actual data revealed the peak region of the unimodal pattern with the greatest species richness at the same height.

Elevational relationship of alpha diversity and beta diversity indices: The outcome of regression of species richness reveals a statistically significant unimodal trend for species richness or alpha diversity against elevation. This result was also supported by outcome of work in Nepal (Bhattarai et al., 2004; Nepali et al., 2020; Subedi et al., 2015) and abroad (Acharya et al., 2011; Grytnes et al., 2006; Lee et al., 2012). In mountainous areas, the hump-shaped structure is a frequently occurring pattern of species (Liang et al., 2020). The observed unimodal pattern in species richness may be predicted accurately by the mid-domain effect, which helps to explain patterns of altitudinal richness. The mid-domain effect is caused by overlapping of species of two or more communities.

Beta diversity is the change in diversity of species between two or more ecosystems in an area. The interpretation and explanation of variation in community composition among sites is intimately tied to the concept of "nestedness" and "turnover" (i.e., beta diversity, Anderson et al., 2011). The Bray-Curtis dissimilarity index represents the species turnover ratio and the Jaccard similarity index represents the nestedness ratio of common species between two communities. The Bray-Curtis dissimilarity index regression result displays a statistically significant but inverted hump-shaped structure. This finding was also supported by result of spatial turn over and elevation (Bhattarai et al., 2004). In contrast to this finding, beta diversity also demonstrated a unimodal link between altitude and the variety of vascular plants in the Faroe Islands, Europe (Fosaa, 2004), as well as a subarctic mountain tundra (Naud et al., 2019). According to Fontana et al. (2020), species turn over reduced in plant and insect groups in pastured grasslands in the European Alps as elevational distance increased.

The regression result of species nestedness or Jaccard similarity index reveals a statistically significant unimodal structure against elevation. According to the hump-shaped structure of species richness and Jaccard's similarity index, the peak was created by the presence of more similar species. This may be due to ecotone effect of two adjoining vegetation. Species richness (i.e. alpha diversity) and beta diversity index of species per 100 m contour elevation show the reverse relation to each other. There was less beta diversity index value due to more species similarity at mid-elevation. Generally, a high beta diversity index indicates a low level of similarity, while a low beta diversity index shows a high level of similarity. Therefore, in this study, alpha diversity per elevation gradients and species turnover (dissimilarity index) of beta diversity exhibit the inverse relationship.

A region that serves as a transition between two forests or ecosystems is known as an ecotone. It is well known that the species richness and composition of a forest ecotone can alter, mostly in sub-alpine regions (Shrestha & Vetaas, 2009), but that a smaller ecotone can also form where two types of forests meet. The transition zone between two vegetation communities is thought to have more species than the neighboring communities (Sharma et al., 2014).

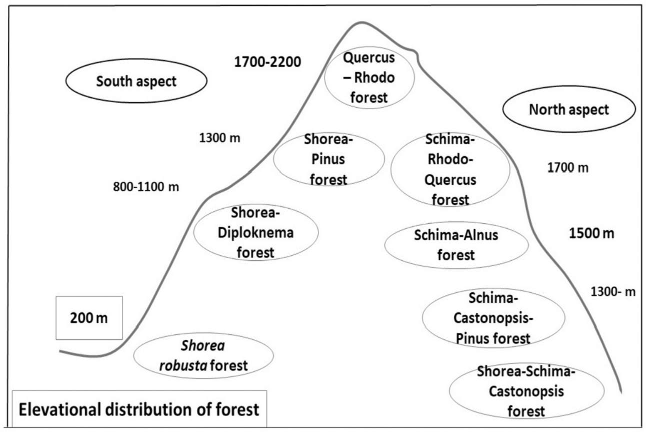


Figure 7: Distribution of forest in two aspects of study area

According to the sketched Figure 7 of this research site, the existence of more comparable species between two close forests also explains the impact of a high species region that produces an ecotone. The decreasing trend of species from the equator to the poles and from low to high elevations is mostly caused by the beta diversity's trend toward decline (Sabatini, 2017). Any location may have high species richness due to either the presence of significant turn covered species (high dissimilarity index value) or high species similarity. The high species richness in this work is experimentally proved by presence of high value of Jaccard similarity index or more similar species at mid-elevation. Interspecific competition may be the main element in the establishment of plant communities at moderate elevations, whereas environmental filtration is the main driver in the formation of plant communities at high and low altitude (Zhang et al., 2016).

According to Var der Plas et al. (2014), sustaining high multifunctionality at local scales depends on other variables than diversity, but at the landscape scale, a high turnover (species dissimilarity or beta diversity) in the community composition of forest plants can aid in preserving as many ecological services as feasible. When a location exhibits a high beta diversity in species presence in any flora, this type of research aids in identifying the area as a biodiversity hotspot. This may be useful for planning a conservation area or running any sustainable initiatives for environmentalists.

Conclusion

This research tried to show the elevational relationship of alpha diversity with beta diversity (species similarity and species turn over) of vascular plant species in Arghakhanchi, west Nepal. Alpha diversity or species richness as well as species similarity in the form of Jaccard similarity index showed the significant unimodal structure with elevation. However, species turn over in the form of Bray-Curtis dissimilarity index showed the reverse relation or the reverse unimodal pattern against elevation. The outcome demonstrates that places with high species richness do not always have substantial species turnover. It is concluded that the existence of significant species similarity causes the unimodal pattern of species richness against elevation gradient to arise.

Author Contributions

Baburam Nepali designed the study, collected and analyzed data and prepared manuscript draft. John Skartveit edited draft and language and gave suggestion. Chitra Bahadur Baniya conceptualized, designed the study, did statistical analysis and draft correction and corresponding and main supervision.

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Appendix: The table showing the alpha diversity species per elevation band and beta diversity indices between two elevation bands (Mid elevation* indicates the mean elevation to indicate the two adjoining elevation bands)

For Alpha diversity		**For Beta diversity**		
Elevation (m)	**Species richness**	**Mid elevation* (m)**	**Beta diversity indices**	
			Jaccard's similarity index	**Bray-curtis dissimilarity index**
200	13			
300	43	250	0.332	0.707
400	62	350	0.545	0.614
500	104	450	0.569	0.544
600	96	550	0.663	0.544
700	162	650	0.579	0.496
800	167	750	0.697	0.463
900	228	850	0.664	0.501
1000	309	950	0.726	0.344
1100	275	1050	0.788	0.324
1200	231	1150	0.722	0.350
1300	172	1250	0.638	0.436
1400	245	1350	0.520	0.414
1500	208	1450	0.607	0.447
1600	188	1550	0.535	0.437
1700	283	1650	0.485	0.407
1800	205	1750	0.591	0.376
1900	191	1850	0.476	0.395
2000	145	1950	0.441	0.460
2100	110	2050	0.357	0.499
2200	48	2150	0.285	0.685

Altitudinal Vascular Species Richness Pattern in West Nepal

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Abstract

Altitudinal species richness pattern is a known phenomenon among biogeographers across the world including Nepal. However, no cross-sectional richness pattern on large scale so far has been studied in Nepal. Thus, this present study has been initiated to understand the vascular species richness pattern in the west (80°04' to 83°E) Nepal. All available information related to vascular plants of the west Nepal were collected first and then interpolated. A total of 3291 vascular species were enumerated from different literatures from altitude below 100 masl around Dhangadi to above 7100 masl around Api mountain, west Nepal. The interpolated vascular species richness was regressed against their respective altitude through an application of generalized linear model (*GLM*). Statistically highly significant unimodal species richness pattern ($p< 0.001$ & $r^2=0.957$) with maximum richness of 1360 species was obtained at 2200 masl. Similar unimodal richness pattern was observed for endemic and non-endemic vascular plants with maximum richness at 3700 masl and 2200 masl respectively. This study resembled general pattern in some extent and differed with specific pattern. There would be many reasons behind these patterns but more likely driven by much drier westerly weather condition.

Key words: Endemic, Interpolation, Maximum richness, Regional, Unimodal

Introduction

Species richness, the number of species confined per unit area, is not uniform in this earth (Gaston, 2000). It is the most widely used, studied, simplest and easily interpretable indicator of biological diversity which is determined by a complex of environmental factors (Whittaker, 1977; Brown et al., 2007). Many factors including geographic (e.g. species pool, dispersal), biotic (e.g. competition, predation, facilitation) and abiotic (e.g. resource availability, environmental heterogeneity, disturbance frequency and intensity) variables affect small-scale species richness (Brown et al., 2007). In general, species richness shows four patterns: decreasing, low plateau, low plateau with a mid-elevation peak and broad mid-elevation peak (McCain, 2009; Zhang et al., 2016).

Numerous hypotheses have been proposed to explain the altitudinal species richness pattern, especially variation between habitats and large scale regions (e.g., the latitudinal diversity gradient) (Mittelbach et al., 2007), area (Wang et al., 2007), disparity of temperature and rainfall (Stevens & Fox, 1991; Acharya et al., 2011), complex topography (Ghazal, 2015), aspect (Sharma et al., 2014), soil composition (Dölarslan et al., 2017). Rahbek (1995, 1997) analyzed three patterns in altitudinal species richness: a monotonic decline, a hump-shaped with a maximum at mid-elevations, and a monotonic incline. Rahbek’s (1995) review on altitudinal species richness pattern showed that a large number of species show mid altitudinal peak in species richness pattern. Unimodal altitudinal species richness distribution pattern seems to be a universal. According to Grytnes & Vetaas (2002), unimodal pattern of species richness with respect to altitude is typical in many mountainous regions, even in Nepal Himalaya. The mid domain nature produces a peak at mid elevation which disrupts the increasing pattern of species richness against altitude resulting into hump shaped unimodal or polymodal forms. Every species has its own life span which is limited in certain distribution range according to their tolerant capacity. The species richness first increases along altitude due to continuous addition of new species and overlapping of their elevation range. But, it decreases after certain altitude due to termination of elevation range of more species and introduction of less species or species accumulation curve according to Ugland et al (2003). Many evidences show that time and ecological influences on diversification rates on both large and small scale species richness patterns (Wiens, 2011).

Nepal’s rich biodiversity is reflection of its unique geographic position (the longest bioclimatic elevation gradients extending from 67 m to 8848 m) within 150–200 km south to north, diverse climatic conditions and great habitat variation (Grytnes & Vetaas, 2002). The occurrence of the east Himalayan vegetation in East Nepal and west Himalayan elements in west Nepal, or the transitional zone between the eastern and western Himalayas make rich in biodiversity (Banerji, 1963; NBS, 2002). Although, the country occupies only about 0.1 percent of global area, yet harbours 3.2 percent and 1.1 percent of the world's known flora and fauna, respectively (MFSC, 2014).

History of botanical explorations in the country shows that such explorations are concentrated in Central and East Nepal (Rajbhandari et al., 2016). The western part of the country with fragile soil structure, more steep and rocky hills and less rain fall are likely to harbour different and unique biodiversity than in other regions. For instance, acidic soil resulted due to dense gymnosperm species (Thomson, 2014) of this region may create unfavorable condition for other species. Moreover, information on biodiversity is crucial to prepare sound development plans that integrate biodiversity conservation issues. Therefore, this study was conducted with aims to (i) generate a baseline on species richness pattern of different taxa of vascular plants in west Nepal. (ii) compare altitudinal species richness pattern of the endemic species with non-endemic vascular plant species.

Materials and Methods

Study Area

This study was conducted in west Nepal. The altitudinal range in west Nepal ranges from below 100 m to above 7100 masl, occupying about 20 % of total land in Nepal. Climatologically, it is warmer and drier than other parts of the country because monsoon in Nepal starts from Bay of Bengal which gradually decreases towards central and western Nepal. The west Nepal (mainly former mid-western and far western development regions) receives decreasing trend of monsoonal rainfall only up to 4 mm during pre-monsoon; up to 30 mm in monsoon and up to 7 mm per year in post monsoon. Some areas in the northern parts of west Nepal observed decreasing trend of rain even in winter (Marahatta et al., 2009). The maximum and minimum rainfall was recorded at Dhandgadi (1888.1 mm/yr) and Jumla (811.4 mm/yr) respectively. The average maximum temperature (30-36° C) and minimum temperature (-10 to -20°C) have been recorded in Nepalgunj and Simikot, Humla respectively in west Nepal (DHM, 2017). So, soil in west Nepal is more fragile and dry which results in some different types of vegetation than the rest of the country. Terai and Siwalik regions (below 1000 masl) consist of tropical forest, containing *Shorea robusta*, *Dalbergia sissoo*, *Acacia catechu*, *Adina cordifolia* etc. Sub-tropical region (1000-2000 masl) is occupied by *Schima walichii*, *Pinus roxburghii*, *Castonopsis indica* etc. Above 2000 m, most parts of west Nepal is covered by gymnosperms (*Pinus wallichiana*, *Cedrus deodara*, *Juniperus* spp., *Abies pindrow*, *Picea smithiana*, *Castonopsis*, *Quercus*, *Rhododendrons* etc. Between 3000 to 4000 m the hills of inner and outer Himalayas are dominated by conifers and *Rhododendron* forests containing *Rosa sericea*, *Salix bhutanesis*, *Daphne volua*, *Prunus cornuta*, *Picea smithiana* etc.

Above 4000 m, trees are absent and vegetation covers mainly consists of grasses, herbs and dwarf shrubs such as *Juniperus indica, Potentilla fruticosa*, shrubby Rhododendrons etc.

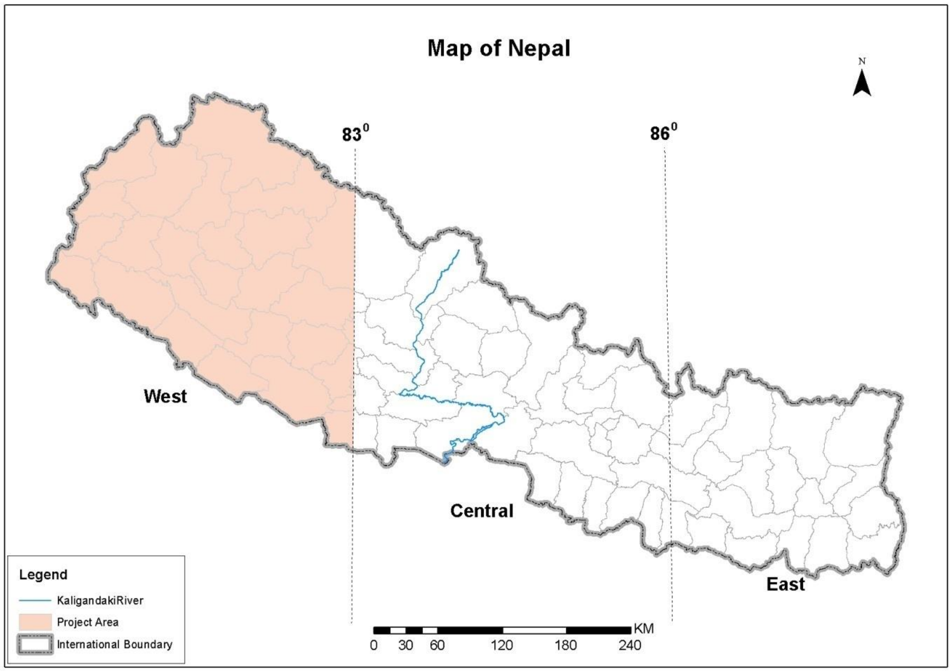

Figure 1. *Map of Nepal showing East, Central and West parts.*

Data sources

Plant Species Resources collection and interpolation

The plant species information of west Nepal were collected from various published research articles (Bartolucci & Dhakal, 1999; Thapa, 2001; Grytnes & Vetaas, 2002; Panthi & Chaudhary, 2002; Bajracharya & Shrestha, 2004; Rajbhandari & Dahal, 2004; Jha, 2007; Rajbhandari & Suzuki, 2008; Rijal, 2008; Bhatta & Chaudhary, 2009; Shrestha & Jha, 2009; Rokaya et al., 2010; Ohba & Akiyama, 2010; Adhikari et al., 2012a; Adhikari et al., 2012b; Satyal & Setzer, 2012; Shrestha & Rai, 2012; Semwal et al., 2014; Pradhan & Bajracharya, 2014; Shaheen et al., 2016; Sangraula et al., 2017); research books and reports and some unpublished data (Niroula, 2004; Baniya, 2010; Singh, 2014). The collected information was corrected on the basis of web pages www.theplantlist.org. and www.catelogueoflife.org.

The altitudinal gradient of west Nepal (80-6200 m) from where plants were reported were divided equally into 62 bands. Between upper and lower elevation limits, the species were counted at each 100 m interval. In this study, total number of species present in each 100 masl band represents as species richness. Species recorded at only a single site were subjectively given an altitudinal range of 100 m.

Similarly, species number of plants on the basis of taxa (dicot, monocot, gymnosperm and ferns or pteridophyte), non-endemic and endemic plants were also determined. This is a macro-scale study that covers the entire elevation range of west Nepal.

Data Analysis

The patterns related to species of different taxa (dicot, monocot, gymnosperm and ferns) and total species of vascular plants as respondents and their altitudes as a predictor variable were analyzed within the framework of Generalized Linear Model *(GLM).* The quasi-poisson family error distribution was applied to remove over dispersion. The assumption of normal distribution of error was conformed after Q-Q diagnostic plots plotted against residuals. The change in deviance follows the F-distribution. R mgcv 1.8-2.2 was used to analyze the non-parametric data of endemic plant species and smoothers were fitted with library *GLM* (Baniya, 2010). Similarly, a Pearson correlation was used to show correlation between altitude and plant species.

Results and Discussion

Vascular Plant Species Richness

A total of 3291 species of vascular plant belonging to 200 Families and 1245 Genera comprising of 2045 herbs, 415 shrubs, 336 trees and 195 climbers were recorded (Table 1). This indicates rich floral diversity in the region. Dicot, monocots, gymnosperms and ferns were represented by 2331, 644, 16 and 300 species respectively. The dicot showed broad elevational distribution range while the gymnosperms had the lowest distribution range (Table 1).

Table 1 *Taxonomic account of floristic diversity of West, Central and East Nepal*

SN	Region	Taxa	Species number	Altitudinal range (m)
1	West Nepal	Total vascular species	3291	<100-6200
		Dicot	2331	<100-6200
		Monocot	644	<100-5800
		Gymnosperm	16	300-4500
		Pteridophyte	300	<100-4800
2	Central Nepal	Total vascular species	5101	<100-8000
3	East Nepal	Total vascular species	4294	<100-8100

Correlation of different vascular taxa, endemic and non-endemic species with altitude

The species of vascular taxa (dicot, monocot, gymnosperm, ferns) and total species showed significant negative relationship (-0.8 to -0.34) with altitude (Table 2). Likewise, endemic species of vascular plants showed significant positive relation (0.30) but non-endemic species showed significant negative relationship (-0.71) with elevation (Table 2).

Table 2 *Summary of correlation of different taxa, endemic and non-endemic vascular plants with respect to altitude*

	Alt	**Dicot**	**Monocot**	**Gymno**	**Ferns**	**Tot_spp**	**Endem**	**Non-end**
Alt	1	-0.65	-0.8	-0.34	-0.65	-0.69	0.3	-0.71
Dicot	-0.65	1	0.96	0.86	0.87	0.99	0.3	0.99
Monocot	-0.8	0.96	1	0.74	0.89	0.98	0.05	0.98
Gymno	-0.34	0.86	0.74	1	0.83	0.85	0.4	0.84
Ferns	-0.65	0.87	0.89	0.83	1	0.91	-0.06	0.92
Tot_spp.	-0.69	0.99	0.98	0.85	0.91	1	0.21	1
Endem	0.3	0.3	0.05	0.4	-0.06	0.21	1	0.18
Non-end	-0.71	0.99	0.98	0.84	0.92	1	0.18	1

Species Richness Pattern of Vascular taxa

Species richness in terms of all taxa and total species of vascular plants increased first when altitude increased. Then, it started to decrease after optimum elevations showing unimodal structure. The total vascular species (r^2=0.957), dicot (r^2=0.939), monocot (r^2=0.931), gymnosperm (r^2=0.945) and ferns (r^2=0.989) attained the maximum richness with 1360 species at 2200 m (Figure 2 E); 965 at 2300 masl (Figure 2 A); 246 species at 2000 (Figure 2 B); 10 species at 2600 m (Figure 2 C) and 156 species at 2100 m (Figure 2 D) respectively.

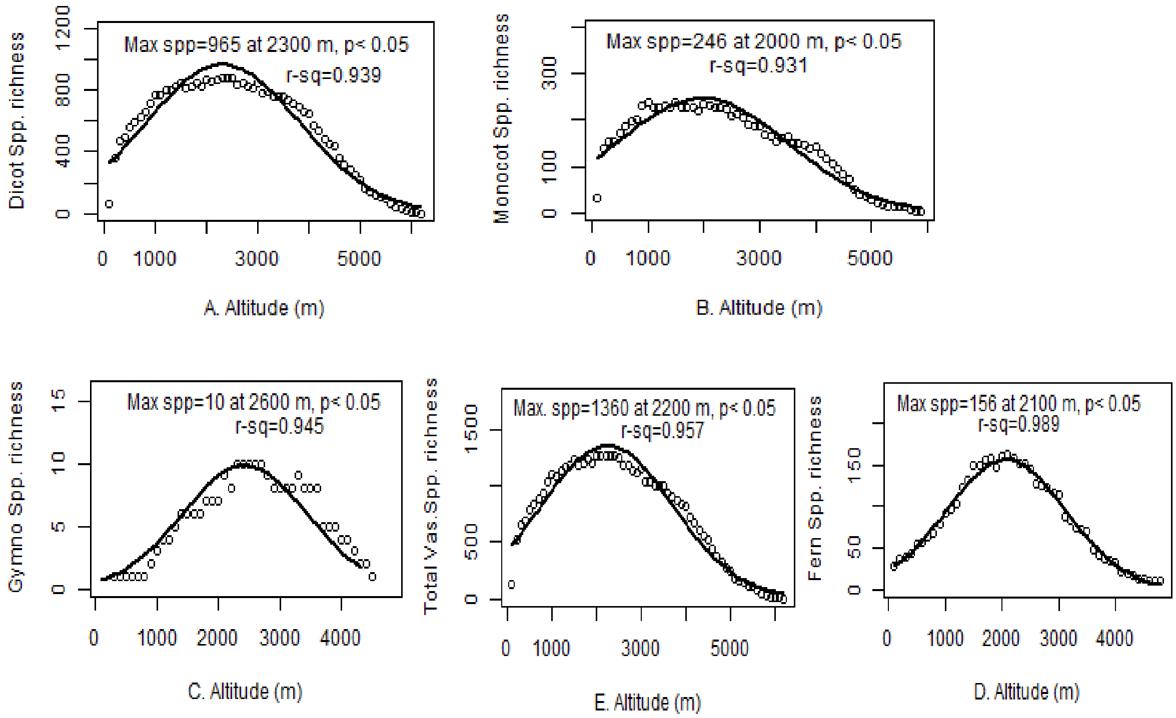

Figure 2 *Pattern of interpolated (E) - total vascular plant species, (A) - dicot, (B)- monocot, (C)- gymnosperm & (D)- ferns species in relation to altitudinal gradient in west Nepal.*

Richness pattern and distribution range of endemic and non-endemic species

A total of 86 endemic and 2982 non-endemic vascular plants were observed which represented respectively 27.6% of total endemic and 51.9 % of total non-endemic vascular plants of Nepal (Table 4). The richness of both endemic species and non-endemic vascular species showed unimodal pattern against elevation. The endemic species (r^2=0.940) attained maximum species (37 spp.) at 3700 masl altitude with right skewedness (Figure 3 A) but the non-endemic species showed maximum species (1339 spp.) at 2200 m with left skewedness (Figure 3 B). The altitudinal distribution range of endemic vascular plant was found less (900-5900 m) than non-endemic species in west Nepal.

Table 4 *Comparison of Species Richness, Elevation distribution range and Elevations of maximum Endemic and Non-endemic species of West Nepal with overall Nepal.*

S.N.	Taxa	Species richness		Elevation range (m)		Elevation of maximum species (m)	
		West Nepal	Overall Nepal	West Nepal	Overall Nepal	West Nepal	Overall Nepal
1	Endemic species	86	312	900-5700	<100-5900	3700	3600
2	Non-endemic species	3205	6174	<100-6200	<100-8100	2200	2100
3	Total vascular species	3291	6486	<100-6200	<100-8100	2200	2100

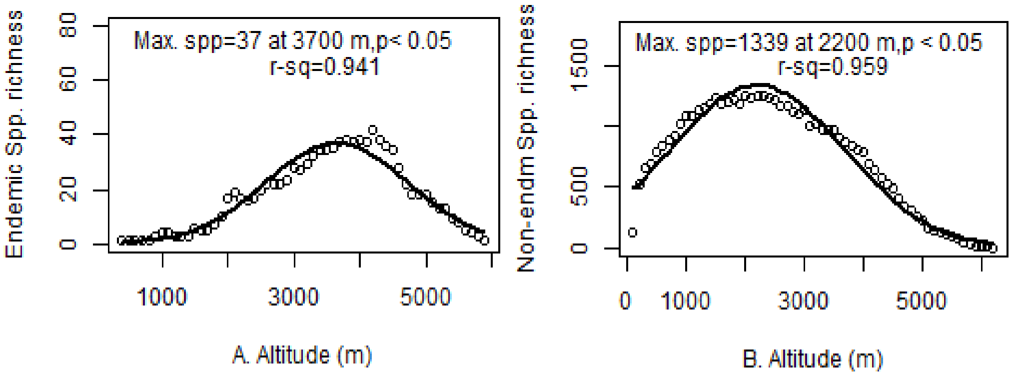

Figure 3 *Pattern of interpolated (A) endemic species& (B) non-endemic species in relation to altitudinal gradient in west Nepal*

This study shows that west Nepal is as rich (3291 species) as East and Central region in floral diversity. The altitudinal range of west Nepal is lower (highest elevation up to 7100 m Api Mountain) in comparison to east and central Nepal which mirror images in occurrence of less altitude of distributional range (up to 6200 m) and less diversity. This coincides with distributional range of plant species which is proportional to overall altitudinal range. Plant growth depends on two important natural resources - soil and water. Soil acts like a reservoir that holds water and nutrients plants need to grow. Soil conditions like soil texture, salinity, soil pH, nutrients etc. are major physical factors that affect plant distribution (Wu et al., 2011). Arid and semi-arid environments which are responsible for fragile ecosystems and certain degree of desertification support low vegetation cover (Zare et al., 2011). Fragile soil structure, more steep and rocky hills and less rain fall in west Nepal could be the main cause for less richness of diversity than other regions. Similarly, acidic soil formed due to dense gymnosperm species of this region may create unfavorable condition for other species. There is significant negative relationship of species of different vascular taxa and non-endemic species with elevation in west Nepal. Only endemic species show the positive relationship against altitude. Sharma et al (2014) found that a positive linear relationship between the native species and altitude. Driessen (2013) also found positive relation of endemic species and negative relation of non-endemic species against altitude in the islands of New Guinea and Borneo. The deviation of species richness with elevation might be associated with the reduction of temperature and productivity (Rahbek, 1995), which results into negative relation between species and elevation.

The richness of all taxa, endemic and non-endemic species of vascular plant show hump shaped pattern with peak richness at the lower half or upper half of the elevation gradient. Similar richness pattern follows in species of most of the mountain regions (Oommen & Shanker, 2005). The skewedness of peak richness is positive in many vascular taxa- dicot, monocot, ferns and total species of vascular plants- but negative in gymnosperm. In general, mountains presenting greater elevation extent are more likely to display unimodal patterns (Guo et al., 2013).

The peak richness altitude of vascular taxa appears between 2100-2600 m in west Nepal. This result coincides with peak richness elevation (1500 to 2500 for flowering plants; 1900 m for ferns) for Nepal (Grytness & Vetas, 2002; Oommen & Shanker, 2005, Bhattarai & Vetas, 2006). Different taxonomic groups exhibit peak at different elevations due to different hard boundaries for individual species (Bhattarai & Vetas, 2006) which probably reflects both physical and physiological constraints. The result concludes that the peak elevation of any plant group is directly proportional to altitudinal distribution range of most species of that group than overall distribution range. The differences in elevation diversity peaks among plants and animals and among their subgroups probably reflect differences both in physiological tolerance and niche partitioning among species groups (Guo et al., 2013).

The peak richness of endemic species appears in 3700 m in west Nepal. It is supported by highest richness of endemic lichen in 4000-4100 masl (Baniya, 2010) and bryophytes at 4250 masl altitude in Nepal. Both endemic and non-endemic species express unimodal structure against altitude. There was negative skewedness in endemic but positive skewedness in non-endemic species. The endemic vascular plant species shows very short elevation distribution range or in narrow ecological amplitude (Bhattarai &

Vetas, 2006) on higher altitudes than non-endemic species (Driessen, 2013). The mid-domain effect (MDE) theory predicts that endemic species show more peak elevation than non-endemics (McCain, 2009). There was no overlap between the peak of endemic species (at 3700 masl) and non-endemic species (at 2200m) with a striking 1500 m difference between the peaks with similar results of endemic and non-endemic species in overall Nepal (Grytnes &Vetaas, 2002). The range of endemic species is constricted due to high anthropogenic pressure, unable to invade in fresh areas (Stevens, 1992) or being isolated due to unfavorable conditions of evolution and assault of new exotic species. Multiple factors are responsible for distribution patterns of different taxa on different places at different spatial and temporal scales.

Conclusion

Altitude was found to have a significant relation with species richness of all vascular taxa, endemic and non-endemic species. Species richness of vascular taxa and non-endemic species showed significant negative relation but endemic species showed significant positive relationship with elevation. The species of all taxa had a unimodal response to altitude. However, the peak elevation having maximum species richness is diverse in different taxa in west Nepal, which is less than those of Nepal and is proportional to the altitudinal range of species. The result concludes that the peak elevation of any plant group is directly proportional to altitudinal distribution range of most species of that group than overall distribution range.

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Appendix 1. Summary of regression of statistics when species richness of each taxon of vascular plants is regressed against elevation. Polynomial first order (1) and second order (2) were tested against the null model

Model	Predictor	Response	Resid DF	Resid. Dev	Df	Deviance	F	Pr(>F)
0	Altitude	Dicot species	61	5630448				
1			60	9453	1	5620995	45210	< 2.2e-16
2			**59**	**1035**	**2**	**5629414**	**194917**	**< 2.2e-16**
0	altitude	Monocot spp	57	360884				
1			56	1801	1	359083	14193	< 2.2e-16
2			**55**	**237**	**2**	**360647**	**48355**	**< 2.2e-16**
0	Altitude	Gymno spp	44	456.31				
1			43	92.59	1	363.72	201.4	< 2.2e-16
2			**42**	**6.46**	**2**	**449.85**	**1702.7**	**< 2.2e-16**
0	Altitude	Fern species	48	147446				
1			47	1625	1	145821	4604.1	< 2.2e-16
2			**46**	**20**	**2**	**147426**	**161480**	**< 2.2e-16**
0	Altitude	Total spp Richness	61	11800329				
1			60	13243	1	11787086	67029	< 2.2e-16 *
2			**59**	**1110**	**2**	**11799219**	**379636**	**< 2.2e-16 ***
0	Altitude	Endemic spp	59	38915				
1			58	1097	1	37819	2183.4	< 2.2e-16
2			**57**	**130**	**2**	**38785**	**6722.5**	**< 2.2e-16**
0	Altitude	Endemic spp	50	3049.33				
1			49	254.52	1	2794.8	606.67	< 2.2e-16
2			**48**	**18.35**	**2**	**3031**	**3736.4**	**< 2.2e-16**

Certificates of Participation in Seminars

1. Attended in International Conference on “Biodiversity, Food Security & Climate Change (ICBFSCC 2023)” organized by Assam Agriculture University, Assam, Jorhat, India.
2. Participated on “National Conference on Integrating Biological Resources for Prosperity” held on 6-7 February, 2020, at Biratnagar, Nepal.
3. Attended on “International Conference on Biodiversity and Bioprospecting” held on June 22-24, at Kathmandu, organized by Department of Plant Resources, Ministry of Forest and Soil Conservation, Nepal.
4. Participated on International Seminar on “ Natural Resources and Agricultural Society in a Climate Change, (NRACC 2019)” held in Kathmandu organized by NORAD, Kathmandu.

Platinum Jubillee Celebration of College of Agriculture, Jorhat

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