



Diversity and distribution of tree species with respect to edaphic and physical factors in *Shorea robusta* Gaertn. forests along the altitudinal gradient

Sujan Chaudhary¹  · Biva Aryal¹

Received: 18 January 2023 / Revised: 5 February 2024 / Accepted: 23 February 2024
© The Author(s) under exclusive licence to Society for Plant Research 2024

Abstract

Changes in population structure, abundance, diversity, and distribution in the forest ecosystem are compounded by topographic variation and edaphic factors. The present study aimed to identify the diversity of tree species and their distribution with respect to topographic and edaphic factors. The study was conducted in three community forests (*Shorea robusta* forest) along the three altitudinal gradients (lower, middle, and higher altitude forests). The study areas recorded 43 tree species under 35 genera and 25 families. Fabaceae had the highest number ($n=7$) of tree species, followed by Anacardiaceae and Combretaceae (4 species each). One-way ANOVA showed that there was a high significant difference ($P=0.004$) in tree species richness among the altitudinal ranges. However, the value of the Shannon Diversity Index (H) was higher (1.078) in higher altitude forest followed by lower (0.966) and middle altitude (0.833). Tree species were distributed with respect to phosphorus, pH, moisture, bulk density, and altitude. The multiple R square value was determined by multiple linear regression to be 0.446 (p value < 0.001). It is evident that the distribution of tree species is influenced by 44.6% of the total variables. The findings of the present study will be essential for planning and putting the required management strategies into practice since abiotic factors that form a plant's basic niches and resources affect how well a species can grow and persist.

Keywords Community Forest · Distribution · Tree species · Soil factors

Shorea robusta Gaertn. is basically known as “Sal” in Nepal, and their forests can be found from a few meters to 1500 m above sea level (Gautam and Devoe 2006). *S. robusta* forests are divided into two types in Nepal on the basis of their physiographical locations (Stainton 1972). The tropical region in Nepal ranges below 1000 m above sea level. The Sal forests that lie in the Tarai region or lower tropical region are called “Tarai Sal Forest (TSF)” or “Lower Tropical Sal Forest” and those situated in the Siwalik or hilly area are known as “Hill Sal Forest (HSF).” *S. robusta* is a prominent species in both forest types, despite the fact that the two Sal Forest types have different tree species compositions (Paudel et al. 2012; Uprety et al. 2023;

Shrestha et al. 2023). Lower tropical Sal forest include associated tree species like *Adina cordifolia*, *Bombax ceiba*, *Cassia fistula*, *Lagerstroemia parviflora*, *Lannea coromandelica*, *Terminalia alata*, *Terminalia bellirica* etc. Riverine Sal forest include *Senegalia catechu* and *Dalbergia sissoo*. However, higher tropical Sal forest or HSF and Churia hill of Sal forest include *Castanopsis indica*, *Schima wallichii*, *Pinus roxburghii*. The *S. robusta* forest has a good variety of plants, including ferns, lianas, fern-like plants, herbs, and shrubs (Gautam and Devoe 2006; Ghimire and Lamichhane 2021). Due to Nepal's current population expansion, haphazard collection of forest products, deforestation, illegal trade in forest products, unsustainable harvesting, overgrazing, and other anthropogenic activity, the country's forests are at serious risk (Bajpati et al. 2018). Particularly, Tarai's forests are under threat as a result of people migrating from the hills to Tarai to settle, who are also to blame for the degradation of forest areas for their daily subsistence (Acharya

✉ Sujan Chaudhary
csujan070@gmail.com

¹ Department of Botany, Tribhuvan University, Amrit Campus, Kathmandu, Nepal

and Shrestha 2011; Bhattarai et al. 2021; Chaudhary and Aryal 2023).

In order to prevent deforestation and the deteriorating condition of forests across the country, the Government of Nepal (GoN) has made a policy to involve local populations in forest management. This policy of Community Forestry (CF) was based on the 1976 National Forestry Plan, but it was first made available in 1978 (Karky et al. 2007). Local communities are protecting the forests that have been handed over to them and, in return, are enjoying the ecosystem services provided by the forest. The ecosystem services include firewood, fodder for livestock, wild foods, medicinal plants, beauty and aesthetic values, economic growth through recreation, and tourism. Moreover, Sal forests are a great contributor to mitigating the effect of climate change by sequestering the huge amount of carbon in their vegetation and soil (Regmi et al. 2021).

Due to topographic variation, edaphic variables, forest productivity, and biological interactions between different species, changes in population structure, abundance, diversity, and distribution in the forest ecosystem are complicated (Saima et al. 2018). In a range of settings, abiotic factors, including topography and soil composition, have a significant impact on plant distribution, and identifying these essential traits is crucial for efficient forest management and biodiversity preservation (Ehrlich 1996). The rapid population expansion, haphazard collection of forest products, deforestation, illegal trade in forest products, unsustainable harvesting, overgrazing, and other anthropogenic activity are putting Nepal's forests at serious risk right now (Bajpati et al., 2018). Particularly, the Sal forest of Terai and Churia hill are under threat as a result of the movement of people from the hills to the Terai region for settlement, who are also to blame for destroying forest areas for their daily needs (Acharya and Shrestha 2011). The present study focused on finding out the diversity and distribution of tree species in Sal forests with respect to edaphic factors, topography and disturbance along the altitudinal gradients. Our findings will contribute to a better understanding of the impact of soil factors, topography, and disturbance on the composition and distribution of tree species, which will help guide community forest management and conservation.

Materials and methods

Study area

The present study was conducted in Ramdhuni Kaljhora community forest (RKCF), Patrangbari community forest (PCF) and Khanidanda Malbase community forest (KMCF) which were regarded as lower, middle and higher altitude

forest, respectively. All study sites were located in the eastern region of Nepal (Fig. 1). In order to conduct preliminary research, the community forests were visited in October and November 2021. Seven community forests in the Sunsari and Dhankuta districts were altogether visited. However, three community forests (Fig. 2) were chosen based on the following requirements: (1) The research area had to be a community forest; (2) *Shorea robusta* had to be present in the forest vegetation, (3) Three forests should be located roughly at altitudes between 300 and 600 m, and above 600 m, and (4) The minimum area of the forest should be 100 hectare.

Further details of study areas have been provided in Table 1.

Sampling design

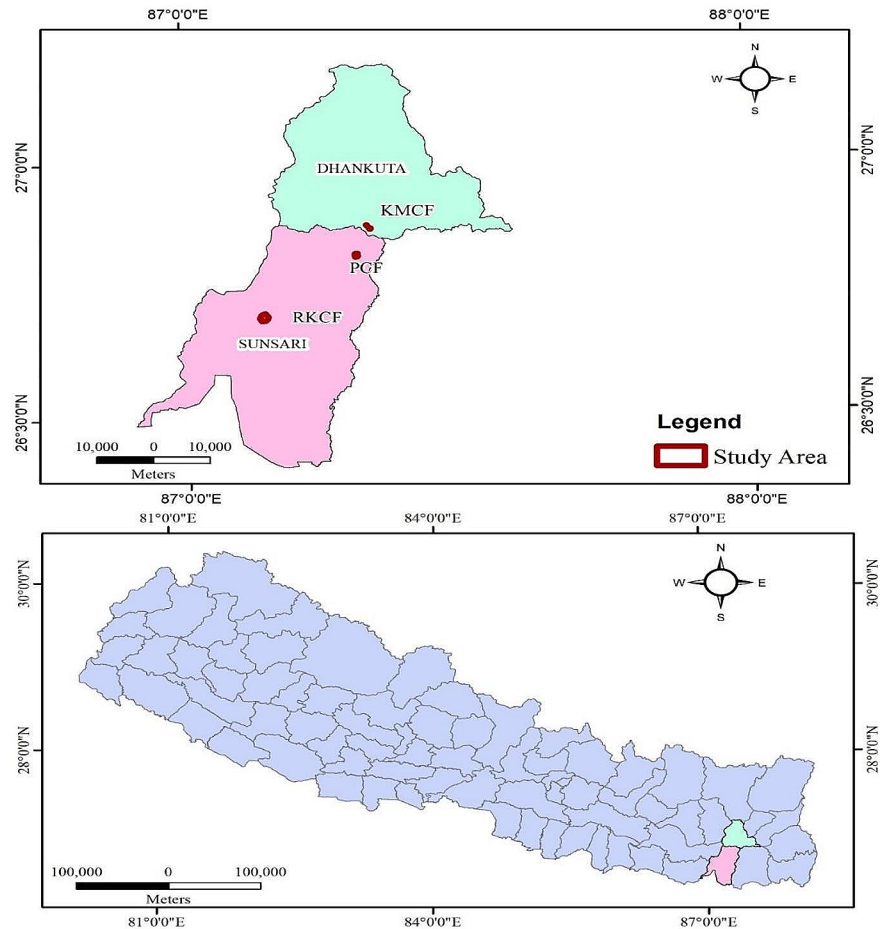
The sampling procedure employed in the research areas was stratified random sampling. With the aid of forest authorities, we divided all the study areas into three blocks based on the species composition, various age blocks, richness of plant species, and geographic locations (Gairhe 2015). We laid ten quadrats in each three blocks randomly. However, the minimum distance between each of the random plot was 50 m. In order to prevent the angle error that could happen in rectangular or square plots in the hill forest, circular plots were used for sampling purposes. The radius of 7 m was used for the study of trees in each plot (Devkota et al. 2021). The investigation was conducted using the map of each community forest as a guide. There were a total of 90 plots studied, with 30 plots in each altitudinal range. Soil samples at a depth of 0–30 cm were taken from all 90 plots in three altitudinal ranges.

Every plot also had a disturbance level measurement, which was scored as 0 (undisturbed), 1 (slightly disturbed), 2 (moderately disturbed), and 3. (highly disturbed). The score was determined simultaneously in the plot based on variables such as tree density, livestock dung and hoof prints, grazing, regeneration, cut trees, axes or other sharp instrument signs, ground vegetation, the presence of industrial waste (such as noodles, bottles, etc.), and branch and twig fall. All of these factors were examined, and a score was given based on the degree of forest disturbance. Some pictures taken while performing field work are shown in Fig. 3.

Community attributes

The important value index (IVI) was calculated with the formula proposed by Zobel et al. (1987). The Shannon-index method was used to determine the diversity of tree species (Shannon and Weaver 1949). The richness and evenness of

Fig. 1 Location map of the study area



the community's trees are both included in the diversity. However, the Shannon Equitability Index (E_H) was used to determine the evenness of tree species.

Soil analysis

We took soil samples from every plot. Four quarters of a single plot's worth of soil samples were taken, and they were easily combined to create a single 750 g sample. The available soil samples were measured for moisture (Piper 1966), soil texture (hydrometric method), soil organic matter (Walkley and Black 1934), total nitrogen content (Jackson 1958), total phosphorus content (Olsen and Sommers 1982), total potassium content (Jackson 1958), soil pH (Cottenie 1980) and bulk density (Brady and Weil 2013).

Data collection and analysis

The data collection was done with the help of local people and the authorities of the community forests in each

forest. The primary data collection was carried out from October to November 2021. The research area's location map was created using ArcGIS version 8.2. The entire descriptive analysis was carried out with MS Excel 2007. For detrended correspondence analysis (DCA) and One-Way Anova, the Shapiro-Wilk test was used to determine whether the data were normal. The axis length and eigen values for the species distribution analysis were quantified using DCA. For DCA, the VEGAN package was utilized in R Studio. Canonical Correspondence Analysis (CCA) was used to observe the species distribution in connection to chosen variables based on eigenvalues and axis length. The significant differences in tree species richness across the three different altitudinal ranges were examined using One-way Anova and the Tukey HSD test. Multiple correlation analyses were performed to observe the relationship among the soil variables. R software, version 4.0.3, was used for all of the statistical analysis.



Fig. 2 Photograph of the study areas (A) Ramdhuni Kalijhora community forest (B) Patrangbari community forest (C) Khanidanda Malbase community forest

Table 1 Details of the study areas

| Community forests | Co-ordinates | Altitude (m) | Area (ha) | Average temperature (°C) | Average precipitation (mm) |
|-----------------------|-------------------|--------------|-----------|--------------------------|----------------------------|
| Ramdhuni Kalijhora CF | 26°41' N 87°08' E | 82–170 | 131.18 | 24.1 | 1953.49 |
| Patrangbari CF | 26°48' N 87°19' E | 440–695 | 186.82 | 24.6 | 2134.2 |
| Khanidanda Malbase CF | 26°51' N 87°21' E | 650–990 | 147.55 | 19.2 | 1118 mm |

Footnote: The data of precipitation have been taken from Department of Hydrology and Meteorology, Kathmandu (average data of 20 years)

Results and discussion

Edaphic and other selected factors

The data on edaphic factors along the altitudinal gradient are provided in Table 2. The relationship between all selected variables was evaluated using multicorrelation (Fig. 4). Organic matter, nitrogen, and sand content were positively correlated with altitude. Moreover, organic matter and nitrogen also had a positive relationship. However, potassium, pH, silt and clay content had a negative correlation with altitude. Bulk density and moisture content were negatively correlated with each other.

A significant difference was observed between the selected variables among the three altitudinal ranges. The soil was loamy, silty loamy, and sandy loamy in low, middle, and high altitudinal range forests, respectively.

Low-altitude forest was composed of 47.76% sand, 34.56% silt, and 17.71% clay, whereas middle and high altitudinal ranges comprised 41.03% and 73.26% sand, 42.93% and 19.96% silt, and 16.03% and 6.63% clay, respectively. The organic matter in the study areas ranged from 2.1 to 4.11%. The organic matter in low, middle, and high altitudinal ranges was 2.10%, 1.79% and 4.11% respectively. Nitrogen content was highest in high altitudinal range (0.20%) and lowest in middle altitudinal range (0.08%). OM and N content were positively associated with an altitude. Higher turnover and uptake of nutrients result in the low organic matter and nitrogen content in soil of Terai Sal forest (Bhattarai and Mandal 2016). The decomposition rate of organic matter and nitrogen in hill Sal forest is very low (Bhattarai and Mandal 2016), resulting in slow net uptake of nutrients. The fact that the Hill Sal forest has a larger quantity of soil organic matter storage might be related to lower soil



Fig. 3 Photographs of the field work

Table 2 Edaphic factors and other selected variables in the study areas, which are given as mean \pm standard deviation. Kruskal-wallis test has been performed to observe the significant difference of the variables among the altitudinal ranges and the dissimilar superscript in a row denotes the significant difference between the variables

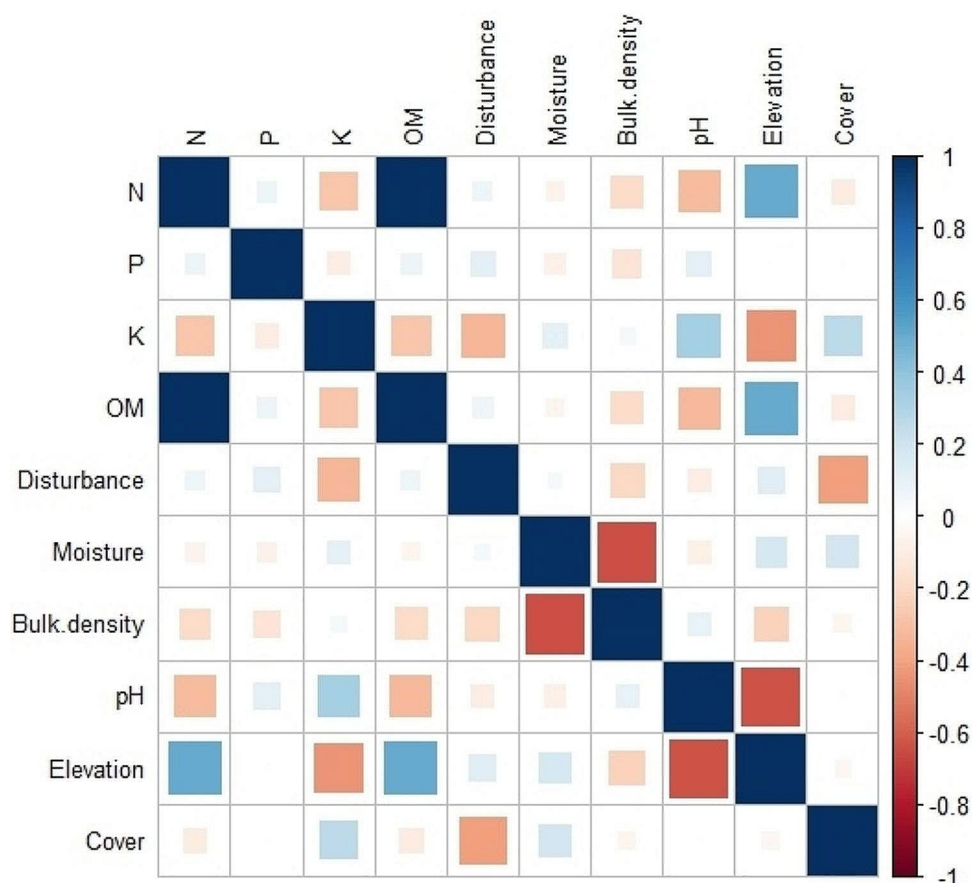
| | Lower altitude | Middle altitude | High altitude | <i>p</i> -value |
|------------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------|
| Organic matter (%) | 2.10 \pm 0.70 ^a | 1.79 \pm 0.78 ^a | 4.11 \pm 1.05 ^b | < 0.001 |
| Nitrogen (%) | 0.10 \pm 0.03 ^a | 0.08 \pm 0.03 ^a | 0.20 \pm 0.05 ^b | < 0.001 |
| Phosphorous (kg ha ⁻¹) | 20.93 \pm 14.76 ^a | 10.17 \pm 6.34 ^b | 21.43 \pm 16.76 ^a | < 0.001 |
| Potassium (kg ha ⁻¹) | 209.24 \pm 63.28 ^a | 209.17 \pm 53.06 ^a | 125.16 \pm 43.16 ^b | < 0.001 |
| pH | 5.27 \pm 0.19 ^a | 4.98 \pm 0.13 ^b | 4.89 \pm 0.22 ^b | < 0.001 |
| Crown coverage (%) | 51.50 \pm 19.12 ^a | 61.16 \pm 16.22 ^b | 48.5 \pm 19.03 ^a | 0.027 |
| Disturbance | 1.66 \pm 0.71 ^a | 1.56 \pm 0.62 ^a | 1.9 \pm 0.71 ^a | 0.167 |
| Moisture (%) | 21.77 \pm 7.25 ^a | 35.97 \pm 24.48 ^b | 22.76 \pm 13.19 ^a | 0.042 |
| Bulk density (g cm ⁻³) | 1.35 \pm 0.18 ^a | 1.33 \pm 0.23 ^a | 1.26 \pm 0.19 ^a | 0.248 |
| Sand (%) | 47.76 \pm 10.01 ^a | 41.03 \pm 7.55 ^a | 73.26 \pm 4.68 ^b | < 0.001 |
| Silt (%) | 34.56 \pm 10.11 ^a | 42.93 \pm 7.06 ^a | 19.96 \pm 3.86 ^b | < 0.001 |
| Clay (%) | 17.71 \pm 6.56 ^a | 16.03 \pm 5.55 ^a | 6.63 \pm 1.79 ^b | < 0.001 |

temperature and moisture, which slows the breakdown of organic matter (Griffiths et al. 2009).

The result showed similar potassium content in the low (209 kg ha⁻¹) and middle altitudinal range (209 kg ha⁻¹). A higher phosphorous content was observed in the high altitudinal range (21.43%) followed by the low (20.93%) and middle altitudinal range (10.17%). Phosphorous (P) content was similar in the forests of low and high altitude. *P* content

did not have any relation to altitude. Ram et al. (2015) have also reported no impact of altitude on *P* content. However, the lower amount *P* in middle altitude forest might be due to the higher consumption of *P* by trees and other plants. The soil of all three forests was acidic in nature. The pH value was 5.27 in the low, 4.98 in the middle and 4.89 in high altitudinal range. The pH trend in this literature also shows the negative relationship between altitude and pH.

Fig. 4 Correlation among different variables in the study areas collectively in all altitudinal ranges ($n=90$)



Ram et al. (2015) have also reported in their study that the pH decreased with increasing altitude in both the rainy and summer seasons. Some bacteria may also be responsible for higher acid soil which produces carbon dioxide, humic acids, and other inorganic acids (Ram et al. 2015).

The disturbance level was found to be higher in the high altitudinal range (1.9) and lower in the middle altitudinal range (1.56). Moreover, the bulk density was 1.35 g cm^{-3} in the low, 1.33 g cm^{-3} in the middle and 1.26 g cm^{-3} in the high altitudinal ranges. The moisture content was highest in middle (35.97%) and lowest in low altitudinal range forest (21.77%) Crown cover was highest in the middle altitudinal range and lowest in the high altitudinal range. Moreover, moisture content was also highest in the middle altitudinal range forest. There was no significant difference between the moisture content of low and high altitude forests. Moisture content was positively related to the crown cover. Moreover, a high percentage of crown cover blocks the sun's rays and does not let them easily reach the ground surface, which causes the moisture to be preserved in the soil. Moreover, the silty loamy texture of the soil in a middle altitude range forest might have helped to bind more water molecules within it due to the large specific area (Brady and

Weil 2013) compared to sandy loamy in a high altitude forest. The large specific area helps to bind more water molecules and other molecules (Brady and Weil 2013). This may be the reason for the high moisture content in the middle altitudinal range. However, lower moisture in low altitudinal range forest may be due to the exposure to high temperatures. Bhattarai (2016) has reported that the soil of Tarai Sal forest experiences a very high temperature in comparison to high altitude forest. Soil texture is the main factor in the movement of air, water, and nutrients through it (Bhattarai and Mandal 2016). Lower moisture content in hill forests may be due to the soil texture and slope. The slope was very high in Sthe hill Sal forest which increased the runoff rate of water. Moreover, the sandy loamy texture may have helped the penetration of water molecules to go deep level of soil and high moisture content was not seen within the depth of 30 cm.

Tree diversity and indices

The study areas recorded 43 tree species under 35 genera and 25 families (Table 3). Fabaceae had the highest number ($n=7$, 16.2%) of tree species, followed by Anacardiaceae

Table 3 List of the tree species with their respective families and presence or absence in three altitudinal ranges

| S.N. | Tree species | Families | RKCF | PCF | KMCF |
|------|--|------------------|------|-----|------|
| 1 | <i>Adina cordifolia</i> (Roxb.) Brandis | Rubiaceae | 1 | 0 | 1 |
| 2 | <i>Albizia lebbek</i> (L.) Benth. | Fabaceae | 0 | 1 | 1 |
| 3 | <i>Albizia lucidior</i> (Steud.) I.C.Nielson ex H.Hara | Fabaceae | 1 | 0 | 0 |
| 4 | <i>Albizia odoratissima</i> (L.f.) Benth. | Fabaceae | 0 | 1 | 0 |
| 5 | <i>Albizia</i> sp. | Fabaceae | 0 | 1 | 1 |
| 6 | <i>Alnus nepalensis</i> D.Don | Betulaceae | 0 | 0 | 1 |
| 7 | <i>Bombax ceiba</i> L. | Malvaceae | 0 | 0 | 1 |
| 8 | <i>Casearia graveolens</i> Dalzell | Salicaceae | 0 | 1 | 1 |
| 9 | <i>Cassia fistula</i> L. | Fabaceae | 0 | 1 | 1 |
| 10 | <i>Castanopsis indica</i> (Roxb. ex Lindl.) A.DC. | Fagaceae | 0 | 0 | 1 |
| 11 | <i>Dalbergia sissoo</i> Roxb. ex DC. | Fabaceae | 0 | 0 | 1 |
| 12 | <i>Dillenia pentagyna</i> Roxb. | Dilleniaceae | 1 | 0 | 0 |
| 13 | <i>Elaeocarpus angustifolius</i> Blume | Elaeocarpaceae | 0 | 0 | 1 |
| 14 | <i>Falconeria insignis</i> Royle | Euphorbiaceae | 1 | 1 | 1 |
| 15 | <i>Ficus benghalensis</i> L. | Moraceae | 0 | 1 | 0 |
| 16 | <i>Ficus semicordata</i> Buch.-Ham. ex J.E.Sm. | Moraceae | 0 | 0 | 1 |
| 17 | <i>Heynea trijuga</i> Roxb. | Meliaceae | 0 | 1 | 0 |
| 18 | <i>Lagerstroemia parviflora</i> Roxb. | Lythraceae | 1 | 0 | 1 |
| 19 | <i>Lannea coromandelica</i> (Houtt.) Merr. | Anacardiaceae | 1 | 0 | 0 |
| 20 | <i>Litsea monopetala</i> (Roxb. ex Baker) Pers. | Lauraceae | 0 | 0 | 1 |
| 21 | <i>Lyonia ovalifolia</i> (Wall.) Drude | Ericaceae | 0 | 0 | 1 |
| 22 | <i>Machilus odoratissima</i> (Nees) Kosterm. | Lauraceae | 0 | 1 | 0 |
| 23 | <i>Madhuca longifolia</i> (J.Koenig ex L.) J.F.Macbr. | Sapotaceae | 0 | 0 | 1 |
| 24 | <i>Mallotus philippensis</i> (Lam.) Mull.Arg | Euphorbiaceae | 1 | 0 | 1 |
| 25 | <i>Mangifera indica</i> L. | Anacardiaceae | 1 | 0 | 0 |
| 26 | <i>Neolamarckia cadamba</i> (Roxb.) Bosser | Rubiaceae | 0 | 1 | 1 |
| 27 | <i>Phyllanthus emblica</i> L. | Phyllanthaceae | 1 | 0 | 0 |
| 28 | <i>Pyrus pyrifolia</i> (Burm.fil.) Nakai | Rosaceae | 0 | 0 | 1 |
| 29 | <i>Rhus chinensis</i> Mill. | Anacardiaceae | 0 | 0 | 1 |
| 30 | <i>Schima wallichii</i> (DC.) Korth. | Theaceae | 0 | 1 | 1 |
| 31 | <i>Schleichera oleosa</i> (Lour.) Oken | Sapindaceae | 1 | 0 | 0 |
| 32 | <i>Semecarpus anacardium</i> L.fil. | Anacardiaceae | 0 | 1 | 1 |
| 33 | <i>Senegalia catechu</i> (L.f.) P.J.H.Hurter and Mabb. | Fabaceae | 0 | 0 | 1 |
| 34 | <i>Shorea robusta</i> Gaertn. | Dipterocarpaceae | 1 | 1 | 1 |
| 35 | <i>Syzygium cumini</i> (L.) Skeels | Myrtaceae | 1 | 1 | 1 |
| 36 | <i>Syzygium nervosum</i> DC. | Myrtaceae | 1 | 0 | 0 |
| 37 | <i>Tectona grandis</i> L.f. | Lamiaceae | 0 | 1 | 0 |
| 38 | <i>Terminalia alata</i> B.Heyne ex Roth | Combretaceae | 1 | 1 | 1 |
| 39 | <i>Terminalia anogeissiana</i> Gere and Boatwr. | Combretaceae | 1 | 0 | 1 |
| 40 | <i>Terminalia bellirica</i> (Gaertn.) Roxb. | Combretaceae | 1 | 1 | 0 |
| 41 | <i>Terminalia chebula</i> Retz. | Combretaceae | 1 | 0 | 0 |
| 42 | <i>Toona ciliata</i> M.Roem. | Meliaceae | 0 | 0 | 1 |
| 43 | <i>Zanthoxylum</i> sp. | Rutaceae | 0 | 1 | 0 |

0 = Absent, 1 = Present

and Combretaceae (4 species each, 9.3%). Moreover, six families had two species each, and sixteen families had one species each (Fig. 5). Lower and middle altitude forests had 17 tree species in each. However, higher altitude forest had the highest tree species richness ($n=29$) (Fig. 6). One-way ANOVA showed that there was a high significant difference ($P=0.004$) in tree species richness among the altitudinal ranges. *Falconeria insignis*, *Shorea robusta*, *Syzygium cumini*, and *Terminalia alata* were found in all three altitudinal ranges. Higher altitude forest was situated in an

ecotone region between tropical and sub-tropical region, which might be the reason for higher tree species richness compared to low and middle altitudinal range forests. In contrast to present study, Kumar and Ram (2005) reported a decrease of species richness along an altitudinal gradient in Uttaranchal, Central Himalaya. It is believed that the variation in species richness is always governed by two or more environmental factors rather than a single factor (Pausas and Austin 2001). A suitable physico-chemical environment for tree species and management strategies of forest users

Fig. 5 Number of plant species under particular families

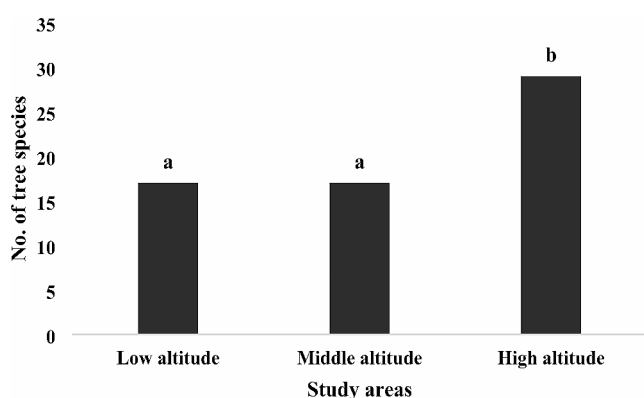
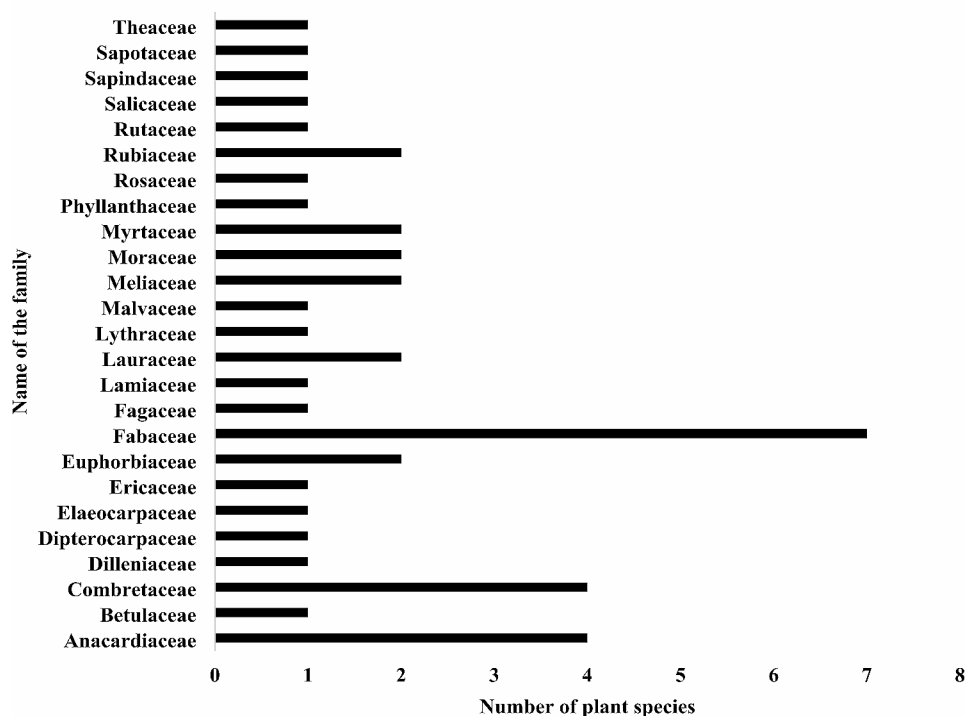


Fig. 6 Tree species richness in the study areas along the altitudinal ranges. The dissimilar superscript above the bar-graph denotes the significant difference between the variables

may be the reasons for the variation in tree species richness in the altitudinal ranges. This also might be due to the fact that the present study was carried out in a small altitudinal range, i.e., 82 to 990 m. The species richness in the Himalaya's increases from low altitude, reaches saturation at middle altitude and decline further (Baniya et al. 2010; Bhattarai et al. 2014). However, the highest species richness in Nepal has been reported in 1500 to 2500 m (Vetaas and Grytnes 2002).

The value of the Shannon Diversity Index (H) was higher (1.078) in higher altitude forest followed by lower (0.966) and middle altitudes (0.833) (Fig. 7). However, the Shannon Equitability Index (E_H) was higher in the lower altitudinal

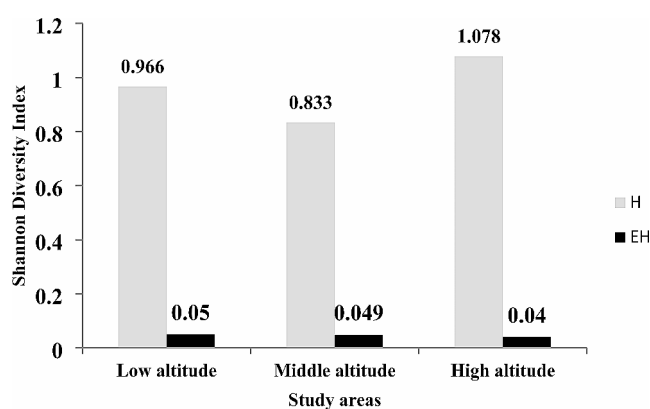


Fig. 7 Shannon Diversity index (H) and Equitability index (EH) of the tree species in three different altitudinal ranges

range (0.05) followed by middle (0.049) and higher altitude forest (0.04) (Fig. 7). The optimum value of Shannon diversity ranges from 1.5 to 3.5 and rarely exceeds 4.5 (Ortiz-Burgos 2016). The higher the value of the Shannon diversity index, the higher the plant diversity. However, none of the diversity index ranges within 1.5 to 3.5, resulting in lower tree diversity in all the sites. Grazing and the collection of firewood and fodder may have resulted in the destruction of forests, contributing to lower tree diversity.

Tree diversity may be affected by management practices as plant species are affected by it (Awasthi et al. 2015). Management activities like thinning, pruning and cutting were effectively performed by lower and middle altitude

forests, which were least observed in higher altitude forest. This might have played an enormous role in the variation in tree diversity in the forests because thinning, pruning, and cutting affect species composition and abundance. A similar result was recorded by Awasthi et al. (2015) where they found low and high Shannon Weiner’s Diversity Index in the managed and unmanaged blocks of community forests respectively. Moreover, the choice of tree plantation by the community forest user groups may have affected the tree diversity in different sites.

Tree distribution

The eigen value and axis length of first axis DCA was 0.458 and 4.107 respectively (Table 4). The eigen values and axis

Table 4 Summary of Detrended correspondence analysis (DCA).

| | DCA1 | DCA2 | DCA3 | DCA4 |
|----------------|-------|-------|-------|-------|
| Eigen values | 0.458 | 0.287 | 0.232 | 0.135 |
| Decorana value | 0.466 | 0.281 | 0.192 | 0.119 |
| Axis lengths | 4.107 | 2.631 | 2.020 | 1.168 |

lengths decreased with the axis number from 1st to 4th. The given parameters of DCA suggested Canonical Correspondence Analysis (CCA) for the analysis of tree distribution with respect to environmental gradients.

The distribution of tree species with respect to selected variables was analyzed using CCA (Figs. 8 and 9). Tree species were distributed with respect to the selected parameters in the present study. The multiple R square value was determined by multiple linear regression to be 0.446 (p

Fig. 8 Tree species distribution with respect to soil factors (P, K, pH, OM, Moisture) collectively among three altitudinal ranges ($n = 90$)

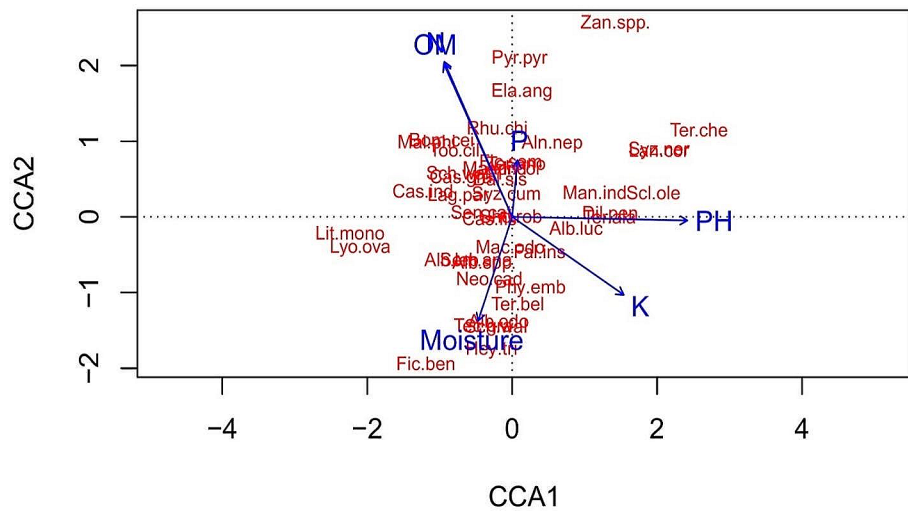
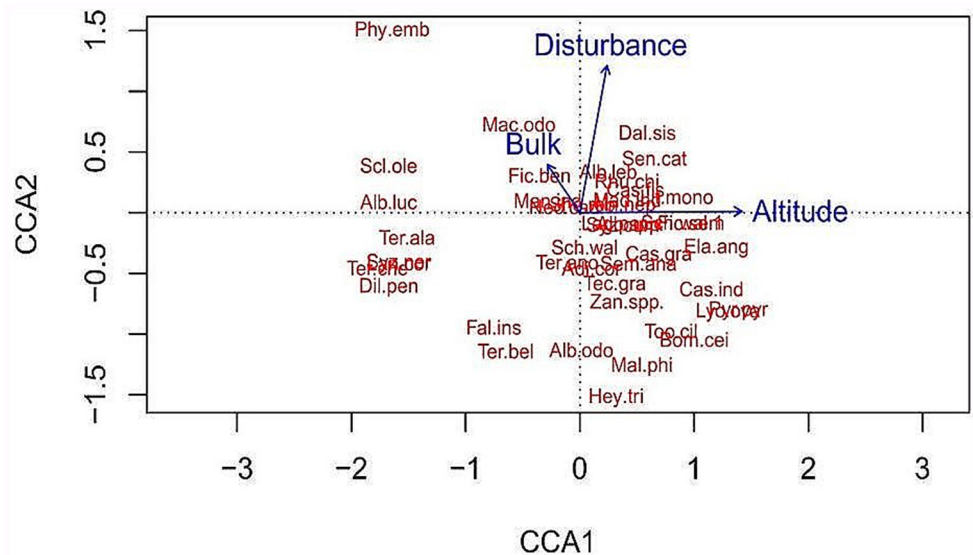


Fig. 9 Tree species distribution with respect to disturbance, bulk density and altitudes collectively in study areas among three altitudinal ranges ($n = 90$)



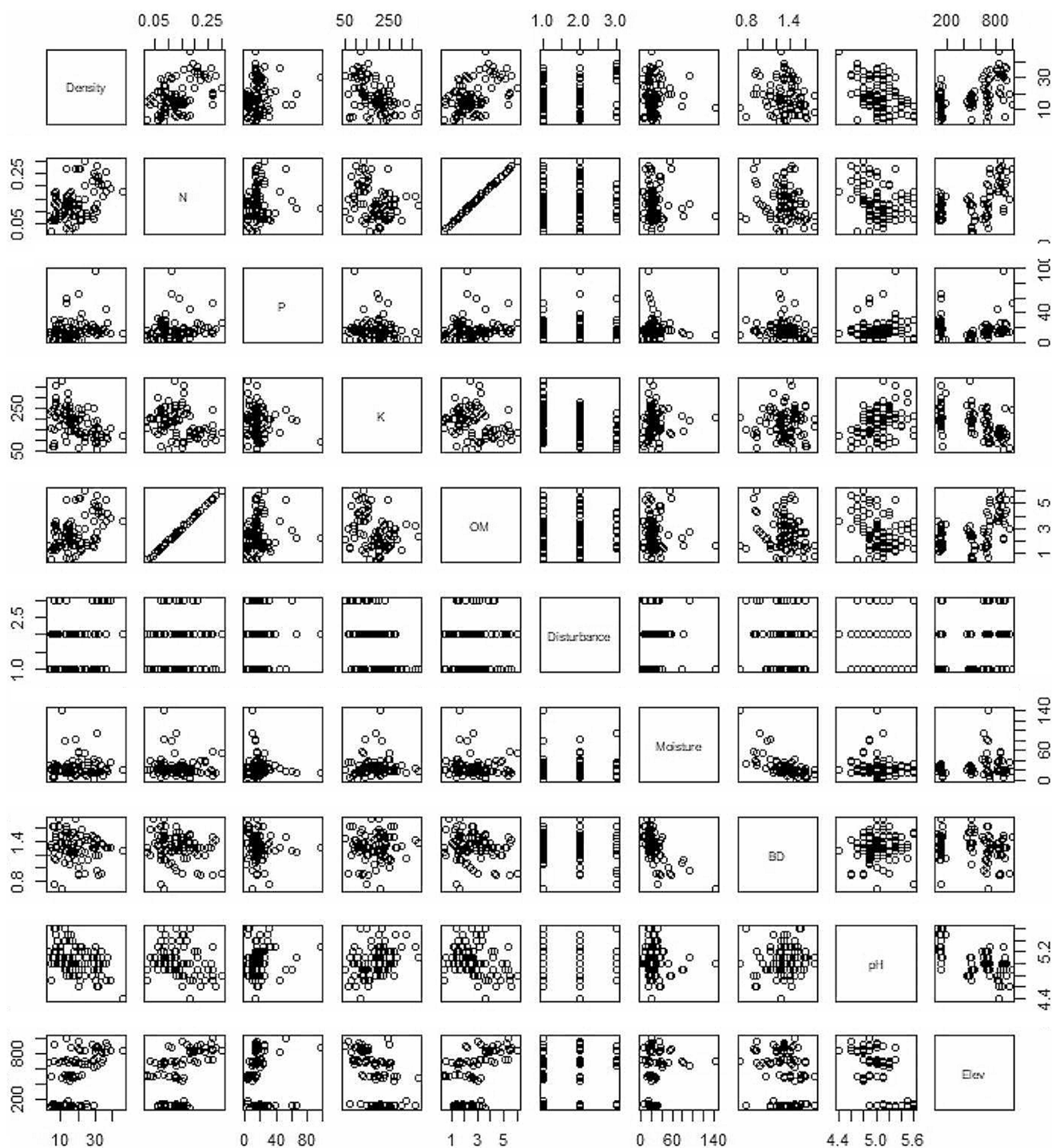


Fig. 10 Plot for the multiple linear regression of density of trees with Nitrogen (N), Phosphorus (P), Potassium (K), Organic matter (OM), Disturbance, Moisture, Bulk density (BD), pH and Elevation (Elev)

value < 0.001). It is evident that the distribution of tree species is influenced by 44.6% of the total variables (Fig. 10). *A. nepalensis*, *F. semicordata*, and *A. cordifolia* were suited to higher phosphorous content. Moreover, *T. alata* and *D. pentagyna* were distributed towards higher pH values and *S. catechu* and *C. fistula* towards lower pH values.

Higher moisture content favored the condition to *F. benghalensis*, *H. trijuga*, *S. wallichii*, *T. grandis* and *A. odoratissima* (Fig. 8). Moreover, the abundance of *M. odoratissima* and *F. benghalensis* was positively correlated to bulk density. *L. monopetala*, *S. wallichii*, *A. nepalensis* and *F. semicordata* were favored by higher altitude. However, *T. bellirica*, *T.*

chebula, *S. oleosa*, *S. nervosum*, and *T. alata* were negatively correlated with altitudes (Fig. 9). The CCA diagram in the study reflects the influence of edaphic factors and altitude in the distribution of tree species. The alteration of soil characteristics had a major impact on tree distribution, which was also supported by Khan et al. (2017). In the current study, the distribution of tree species in distinct spatial patterns in relation to variables reveals the impact of edaphic and abiotic factors. The present result was in agreement with the study of Haq et al. (2022), where they have reported the distribution of tree species with respect to edaphic and topographical factors. The variations in soil types and their chemical, physical, and biological qualities can be found along the altitudinal gradient, where bioclimatic conditions can change quickly and over short distances influencing the spatial distribution of tree species (Hegazy et al. 1998; Davies et al. 2008). A variety of population and community processes can be impacted by due disturbance over a variety of temporal and geographical scales, with potential consequences for biodiversity conservation.

Numerous ecosystem services and functions are offered by trees in the forest. They also help to maintain the water and carbon cycles and also support a significant portion of the global biodiversity, offer a wide range of cultural services, and offer ample opportunities for leisure activities. Any forest stand's current tree diversity indicates the site's historical background and the footprint of community forest management. Therefore, this study may be the tool to test the efficiency of the management of the forest authorities. Moreover, Ecosystem needs diversity of trees to be healthy. A forest's ability to make better use of its resources is enhanced when it harbors a diversity of tree species. This is due to the fact that various species have varying resource requirements and occupy different niches. These are the reasons to maintain healthy tree diversity in the community forests by the community forest user groups to keep the forest healthy and make it sustainable.

Conclusion

The present study concluded that the tree diversity was highest in high altitude forest in the eastern Nepal. In the current study, tree species were distributed according to the parameters that were chosen. Specifically, the spatial distribution of tree species was highly influenced by phosphorus content, pH, moisture, bulk density and altitudinal gradient. The results of the current study will be crucial in implementing management techniques because abiotic elements that create a plant's fundamental niches and resources that allow a species' individuals to survive and determine how well it will thrive. Moreover, community forest user groups

would be introduced with the tree diversity of their forest and motivate them to make a proper plan for conservation of forest diversity and make a strict rule against the deforestation, illegal harvesting and cutting down of timbers, illegal encroachment, soil pollution and other negative impact over forest.

Acknowledgements We appreciate the assistance with data collection and fieldwork provided by Nabin Singh Karki, Chiranjibi Dangi, Saroj Adhikari, Sanju Neupane, Gyanu Thapa Magar, and Sanu Magar. We also want to express our gratitude to the three sub-division offices for supplying us with the essential details and setting up a forest guide. We also wish to express our gratitude to the Nepal Academy of Science and Technology (NAST), which contributed funding to our study.

Declarations

Conflict of interest The authors declare to have no any conflict of interest.

References

- Acharya R, Shrestha BB (2011) Vegetation structure, natural regeneration and management of Parroha community forest in Rupandehi district. *Nepal Sci World J* 9(9):70–81
- Awasthi N, Bhandari SK, Khanal Y (2015) Does scientific forest management promote plant species diversity and regeneration in Sal (*Shorea robusta*) forest? A case study from Lumbini collaborative forest, Rupandehi, Nepal. *Banko Janakari* 25(1):20–29
- Bajpai O, Dutta V, Chaudhary LB, Pandey J (2018) Key issues and Management Strategies for the conservation of the Himalayan Terai forests of India. *Int J Conserv Sci* 9(4)
- Baniya CB, Solhøy T, Gauslaa Y, Palmer MW (2010) The elevation gradient of lichen species richness in Nepal. *Lichenologist* 42(1):83–96
- Bhattarai KP (2016) Decomposition, nutrient release and N-mineralization in Sal (*Shorea robusta* Gaertn.) forests of Jhapa and Ilam districts, eastern Nepal. (Doctoral dissertation Central Department of Botany, Tribhuvan University, Kathmandu, Nepal)
- Bhattarai KP, Mandal TN (2016) Effect of altitudinal variation on the soil characteristics in Sal (*Shorea robusta* Gaertn.) Forests of eastern Nepal. *Our Nat* 14(1):30–38
- Bhattarai P, Bhatta KP, Chhetri R, Chaudhary RP (2014) Vascular plant species richness along elevation gradient of the Karnali River valley, Nepal Himalaya. *Int J Plant Anim Environ Sci* 4(3):114–126
- Bhattarai S, Pant B, Laudari HK, Rai RK, Mukul SA (2021) Strategic pathways to scale up forest and landscape restoration: insights from Nepal's tarai. *Sustainability* 13(9):5237
- Brady NC, Weil RR (2013) *Nature and Properties of soils*. Pearson New International Edition PDF eBook, Pearson Higher Ed, The
- Chaudhary S, Aryal B (2023) Factors affecting the tree and soil carbon stock in *Shorea robusta* Gaertn. Forests along the elevational gradient in Eastern Nepal. *Acta Ecologica Sinica*
- Cottenie A (1980) Soil and plant testing as a basis of fertilizer recommendations (No. 38/2)
- Davies RG, Barbosa O, Fuller RA, Tratalos J, Burke N, Lewis D, Gaston KJ (2008) City-wide relationships between green spaces, urban land use and topography. *Urban Ecosyst* 11:269–287
- Devkota MD, Shrestha LJ, Sharma KP (2021) Thesis Abstracts and Proposal Guidelines. 1st edition. Department of Botany, Tribhuvan University, Amrit Campus, Kathmandu, Nepal

- Gairhe P (2015) Tree Regeneration, Diversity and Carbon Stock in Two Community Managed Forests of Tanahun District, Nepal. M.Sc. Thesis, Central Department of Botany, Tribhuvan University, Kathmandu, Nepal
- Gautam KH, Devoe NN (2006) Ecological and anthropogenic niches of Sal (*Shorea robusta* Gaertn. f.) forest and prospects for multiple-product forest management—a review. *Forestry* 79(1):81–101
- Ghimire P, Lamichhane U (2021) Plant species diversity and crown cover response to regeneration composition in community managed forest. *Asian J Forestry* 5(1)
- Griffiths RP, Madritch MD, Swanson AK (2009) The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): implications for the effects of climate change on soil properties. *For Ecol Manag* 257(1):1–7
- Haq SM, Tariq A, Li Q, Yaqoob U, Majeed M, Hassan M, Fatima S, Kumar M, Bussmann RW, Moazzam MF, Aslam M (2022) Influence of Edaphic Properties in determining Forest Community patterns of the Zabarwan Mountain Range in the Kashmir Himalayas. *Forests* 13(8):1214
- Hegazy AK, El-Demerdash MA, Hosni HA (1998) Vegetation, species diversity and floristic relations along an altitudinal gradient in south-west Saudi Arabia. *J Arid Environ* 38:3–13
- Jackson ML (1958) *Soil chemical analysis* prentice Hall. Inc., Englewood Cliffs, NJ. 498: 183–204
- Karky BS, Banskota K, Karky B, Skutsch M (2007) Case study of a community-managed forest in Lamatar, Nepal. Reducing Carbon Emissions through Community-managed Forests in the Himalaya, pp 67–79
- Khan M, Khan MS, Ilyas M, Alqarawi AA, Ahmad Z, Abd-Allah FE (2017) Plant species and community's assessment in interaction with edaphic and topographic factors; an ecological study of the mount Eelum District Swat. *Pakistan SJBS* 24:778–786
- Kumar A, Ram J (2005) Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. *Biodivers Conserv* 14(2):309–331
- Olsen SR, Sommers LE (1982) Phosphorus. In: Page AL, Miller RH, Keeney DR (eds) *Methods of Soil Analyses: Part 2 Chemical and Microbiological Properties*, pp 403–430
- Ortiz-Burgos S (2016) Shannon-weaver diversity index. *Encyclopedia Estuaries* 572–573
- Paudel PK, Bhattarai BP, Kindlmann P (2012) An overview of the biodiversity in Nepal. *Himalayan biodiversity in the changing world*, pp 1–40
- Pausas JG, Austin MP (2001) Patterns of plant species richness in relation to different environments: an appraisal. *J Veg Sci* 12(2):153–166
- Piper CS (1966) *Soil and plant analysis*. Hans, Bombay
- Ram SS, Dipesh R, Upendra B, Lekhendra T, Ranjan A, Sushma D, Prakriti S (2015) Physico-chemical characteristics of soil along an altitudinal gradients at southern aspect of Shivapuri Nagarjun National Park, Central Nepal. *Int Res J Earth Sci* 3(2):1–6
- Regmi S, Dahal KP, Sharma G, Regmi S, Miya MS (2021) Biomass and Carbon Stock in the Sal (*Shorea robusta*) forest of Dang District Nepal. *Indonesian J Social Environ Issues* 2(3):204–212
- Saima S, Altaf A, Faiz MH, Shahnaz F, Wu G (2018) Vegetation patterns and composition of mixed coniferous forests along an altitudinal gradient in the Western Himalayas of Pakistan. *Aust J Forensic Sci* 135:159–180
- Shannon CE, Weaver W (1949) *The mathematical theory of communication*. University of Illinois Press, Champaign
- Shrestha S, Gautam TP, Raut JK, Goto BT, Chaudhary C, Mandal TN (2023) Edaphic factors and elevation gradient influence arbuscular mycorrhizal colonization and spore density in the rhizosphere of *Shorea robusta* Gaertn. *Acta Ecol Sin*. <https://doi.org/10.1016/j.chnaes.2023.05.011>
- Stainton JDA (1972) *Forests of Nepal*. Hafner Publishing Company
- Uprety Y, Tiwari A, Karki S, Chaudhary A, Yadav RKP, Giri S, Shrestha S, Paudyal K, Dhakal M (2023) Characterization of forest ecosystems in the chure (Siwalik Hills) landscape of Nepal Himalaya and their conservation need. *Forests* 14(1):100
- Vetaas OR, Grytnes JA (2002) Distribution of vascular plant species richness and endemic richness along the himalayan elevation gradient in Nepal. *Glob Ecol Biogeogr* 11(4):291–301
- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci* 37(1):29–38
- Zobel DB, Jha PK, Behan MJ, Yadav UKR (1987) *A practical manual for ecology*. Ratna Book Distributors, Kathmandu, Nepal, p 149

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.