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RECEIVED 28 March 2023

ACCEPTED 13 June 2023

PUBLISHED 21 July 2023

## CITATION

Hashim M, Bushra E, Dasti AA, Abbasi A, Ali HM, Maqsood S, Farooq TH, Aslam A, Abbas Z and Khan MT (2023) Exploration of species diversity and vegetation pattern in temperate conifer forests along altitudinal gradients in the Western Himalayas.  
*Front. For. Glob. Change* 6:1195491.  
doi: 10.3389/ffgc.2023.1195491

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# Exploration of species diversity and vegetation pattern in temperate conifer forests along altitudinal gradients in the Western Himalayas

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The moist temperate forests extend along the whole length of outer ranges of Himalaya between the subtropical pine forests and sub-alpine timberline formation with a rainfall from 400 mm to 800 mm. The altitudinal range is from 1500 m to 3000 m. The floristic variation in these Himalayan forests is poorly understood especially in the study area. Species composition may be either unpredictable or it may correspond to environmental heterogeneity. Vegetation from 144 stands in between 2000 – 2700 m altitude was sampled. Soil samples were collected to document edaphic conditions. Soils were physically and chemically analyzed. Ordination (DECORANA) and classificatory techniques were used to analyze the vegetation data. No clear disjunct vegetation patterns emerged from these analyses. The major axes brought out by the ordination were related to altitude and although it is possible to relate the units of classification to broad soil types. Soil chemical properties, litter cover and rockiness were significantly associated with the vegetation variation along an altitudinal gradient. The application of classification to the ordination allowed the interpretations of the vegetation variation in terms of topography and predictable climatic factors such as rainfall, wind speed and extent of snow accumulation. The vegetation patterns revealed have been discussed in relation to the general problem of plant community definition in continuous forest type. Our results demonstrate the overlapping rather than clearly discrete boundaries between the vegetation types and species distributions. This overlapping nature of the vegetation types are discussed in terms of overlapping environmental preferences of the species. Our results are consistent with notion that species separate edaphically and landscape scale within the uniform looking forest. This view maintains that differences in soil within the forest are distinct enough to favor different species, and thus create numerous floristically differentiated forest patches along the altitudinal gradients. The findings that non obvious but distinct floristic and edaphic variation exist within the Himalayan moist temperate forests at the landscape scale have important practical implications for forest management.

In biodiversity conservation a high degree of habitat heterogeneity implies an increased need for wide-scale information on species distribution and endemism patterns to better assess where the different habitats are, which species they harbor, and where conservation efforts should be concentrated. The overlapping nature of vegetation types and hazy boundaries of the plant communities implies that plant ecologists must continue to attempt the difficult definition of hazy boundaries.

#### KEYWORDS

mountain ecosystem, species distribution, multivariate analysis, Western Himalayas, distribution pattern, composition

## 1. Introduction

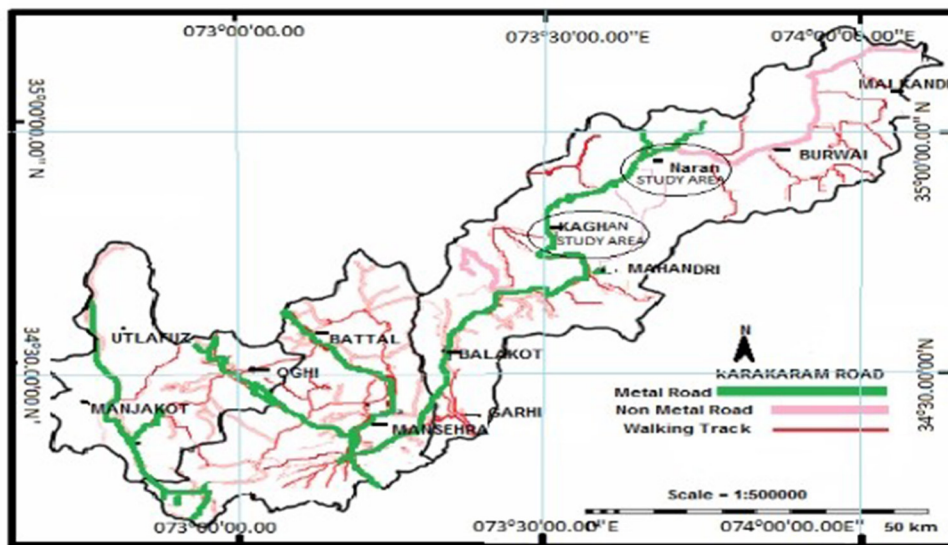
In recent decades, vegetation ecologists have become increasingly interested in recording and understanding mountain vegetation species composition and spatial structure. Owing to the interference of several influences in the high mountain vegetation pattern, the driving factors of the vegetation pattern always remain a topic of debate (Wazir et al., 2008; Saima et al., 2009; Khan et al., 2011, 2012).

In mountain landscapes, altitude is the most important factor that influences habitats, climate, and flora contrasts. Altitude represents a complex combination of related variables such as topography, aspect, soil types, and other environmental features that further affect vegetation composition (Dasti et al., 2007; Wazir et al., 2008; Saima et al., 2009). Ellu and Obua (2005) described how different altitude and slope aspects encounter species diversity. Kharkwal et al. (2005) pointed out that the elevation gradient and its linked geo-climatic variables like precipitation and temperature determine species diversity and community composition. Topographic heterogeneity is also considered an important factor in temperate mountain landscapes that shape phytodiversity, as they strongly influence the length of the growing season related to temperature (Dasti et al., 2007; Wazir et al., 2008; Saima et al., 2009). Downslope movement and distribution of soil water contents depend on the ratio of a rocky surface area to soil volume and the spatial variation in runoff pattern. Redistribution of rainfall water by runoff from some areas depends on rainfall intensity and the surface's infiltration rate.

In most Himalayan forests, runoff accumulation occurs at various scales (Yair and Shahak, 1982; Wazir et al., 2008). Thus, niches and habitats of various kinds and sizes are formed, which determine the structure and composition of vegetation (Orshan, 1986). The distribution patterns of runoff determine the differences in vegetation type and influence plant assemblage (Dasti et al., 2007; Wazir et al., 2008). Besides the runoff pattern, strong winds and snowpack distribution at high altitudes significantly shape plant communities (Tanner et al., 1990; Ahmad et al., 2006; Wazir et al., 2008). The results of previous studies (Tanner et al., 1998; Wazir et al., 2008; Saima et al., 2009; Khan et al., 2012) showed continuous variations in composition across a broad range from lower blue pine canopied forest to upper, relatively open *Abies pindrow* formation.

We used modern data analysis techniques to assess the compositional patterns of plant communities in such a complex landscape. These approaches help summarize the gradients in data sets, assisting in formulating hypotheses and testing their validity (Odgaard and Rasmussen, 2000). Many studies have explored variations in species diversity and soil nutrient concentrations along altitudinal gradients using numerical techniques (Khan et al., 2011; Ping et al., 2013; Saima et al., 2018). Sharma et al. (2009) described the species distribution pattern in India's Garhwal forest of the Himalayas. Bhattarai et al. (2014) investigated species diversity in Nepal's Karnali River Valley in the Himalayas. Shaheen et al. (2011) studied species diversity, community structure, and distribution patterns in Kashmir, Pakistan's Western Himalayan Alpine pasture. Ummara et al. (2013) quantitatively analyzed understory vegetation from only 22 different Shogran Valley reserve forest sites. Raja et al. (2014) described the floristic composition of Ayubia National Park from 27 sampling stands (sites). Jadoon et al. (2017) described ecological gradient analyses of plant associations in the Thandiani reserve forests of the Western Himalayas, Pakistan, using 50 sampling stands. Saima et al. (2018) conducted research to quantify the diversity of species and boundaries of plant communities along the altitudinal gradient in the Shogran Valley reserve forest, while Rahman et al. (2019) explored the floristic diversity of Manoor Valley (Naran). Qadir et al. (2020) researched the anthropogenic effects on natural plant biodiversity distribution and diversity patterns, particularly along the sides of the road in pine forests. Noor et al. (2021) explored the structure and vegetation composition of the forest located in Murree Hills, Punjab, Pakistan. Ahmad et al. (2021) studied the structure and vegetation composition of the Himalayans' moist temperate forest, Kaghan Valley. In other parts of the world, Wani et al. (2023) conducted research to quantify the diversity and compositional patterns in the Kashmir Himalaya.

Although all these studies add significant literature to the topic, studies related to species diversity and richness using a multivariate analysis of the study area are missing and confined to the single forest type due to its remote location and inaccessibility of tracks. Moreover, no information is available regarding a long transect along the elevation gradient from low-level blue pine forests to upper timberline fir forests in these temperate mountain areas. Besides these, we have attempted to elucidate how vegetation changes along the pronounced environmental gradient across the three reserved forest types covering an area of 3,500 Km<sup>2</sup>. We aimed to



**FIGURE 1**  
 A map of the study area depicting sampling localities in circles. Sampling sites for lower Western Himalaya temperate forests (low-level blue pine forests), mid-*Cedrus deodara* forests, Kaghan, and upper-west Himalayan fir forests (upper *Abies pindrow* forests, Naran) are shown in circles.

relate vegetation distribution to topography and soils along an altitudinal gradient and examine some environmental factors for their correlation with the vegetation pattern in our study area.

## 2. Materials and methods

### 2.1. Study area

The valley of Kaghan (34.5417° N, 73.3500° E) is located in the mountains of the Western Himalayas, Pakistan with an elevation range of 650–4,170 m a.s.l (Figure 1). The valley is enveloped by the lower Himalayan mountain range, resulting in an alpine climate and the prevalence of pine forests and alpine meadows. The natural range of temperate forests covers an extensive area of the northwestern Himalayas in Pakistan, India, China, Nepal, and Bhutan. The area is located on gneisses and schists, extending over granites, limestones, and quartzite of the Precambrian age (Champion et al., 1965). The region’s topography is a mosaic of rocky hills, rock outcrops, wetlands, and glaciated lakes of varying sizes (Hussain and Illahi, 1991).

The environment varies widely along the altitudinal gradient (Table 1). There is a considerable year-to-year climatic variation, especially in rainfall and winter snow accumulation. The overall climate of the study area is classified as temperate continental, with an average frost-free growing period of 204 days from April to October. The average annual precipitation for the area is 1,200 mm, with 65% falling as rain from May to August. However, an appreciable amount is brought in during the winter and spring. On average, precipitation is greater at low altitudes than at high altitudes, while temperatures show the opposite trend (Figures 2, 3).

**TABLE 1** Plant families with the highest number of genera and species (dominant).

Family	Number of genera	%	Number of species	%
Asteraceae	14	22.22	16	10.39
Lamiaceae	12	19.05	14	9.09
Rosaceae	09	14.29	12	7.79
Fabaceae	08	12.70	09	5.84
Ranunculaceae	06	9.52	08	5.19
Polygonaceae	05	7.94	09	5.84

In the study area, there are certain dry inner valleys that remain unaffected by the monsoon, leading to the transition to dry temperate forests. In these areas, the snowmelt provides sufficient moisture to sustain the soil during the summer months. Most of the trees and shrubs found in the outer regions of the moist temperate forests do not extend into the inner dry valleys. Overall, the vegetation in these areas undergoes significant changes, warranting a distinct classification of dry and wet temperate forests separately. However, it is important to note that there is no definitive boundary between the moist and dry temperate forests as they gradually transition into one another.

The moist temperate conifer forests in Pakistan (N 34° 38.38/ latitudes and E 73° 33.11/ longitudes) lie within an elevation range of 1,500 to 3,000 m above sea level and receive 400–800 mm of annual rainfall. The topmost characteristic of these forests is the extensive development of coniferous species, which follows a typical structural sequence along the altitudinal gradients. Continuous canopy prevails at lower elevations (close forest zone).

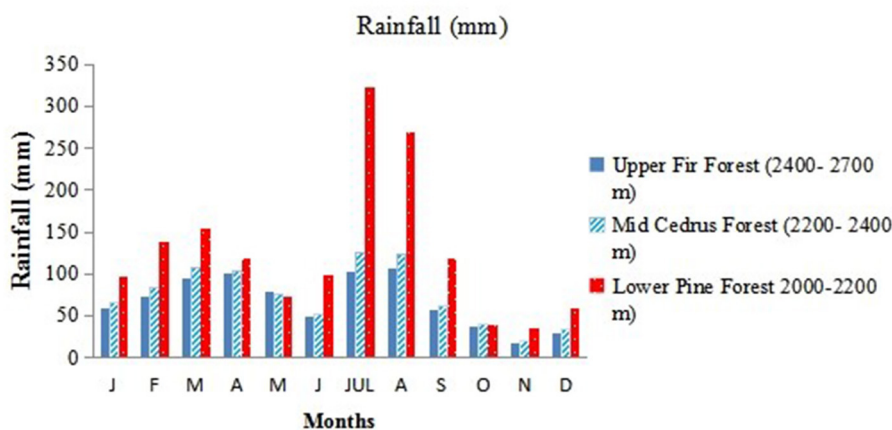


FIGURE 2 Mean monthly rainfall distribution of three forest types: low-level blue pine forests (lower pine forests), mid-*Cedrus deodara* forests (mid-*Cedrus* forests), and upper *Abies pindrow* forest (upper fir forests) along an altitudinal gradient.

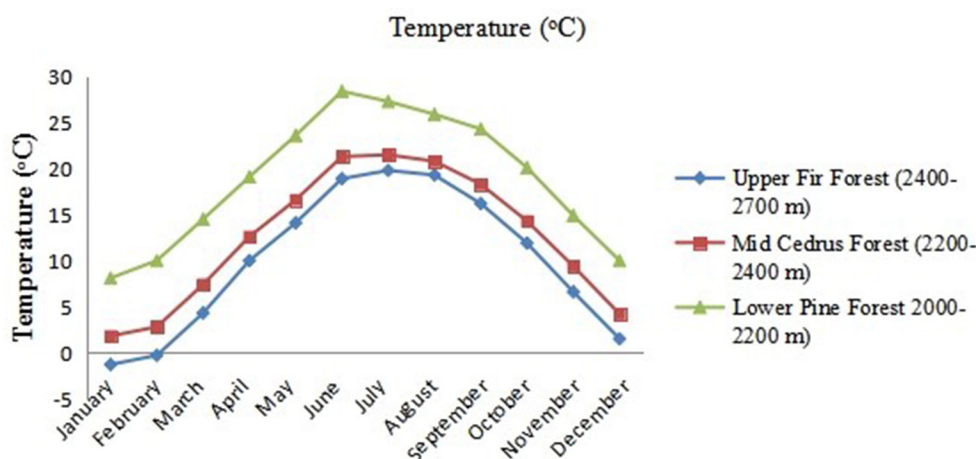


FIGURE 3 The mean monthly temperature of three forest types: low-level blue pine forests (lower pine forests), mid-*Cedrus deodara* forests (mid-*Cedrus* forests), and upper *Abies pindrow* forests (upper fir forests) along an altitudinal gradient.

At an altitude of 3,000 m, the forest canopy becomes fragmented, and the crowns of individual trees generally do not overlap forming woodland zone. Noticeably, this woodland zone was followed by herbaceous pastures (Alpine zone). Commonly, these forests consist of different plant species that exhibits considerable amount of overlap, because these species have specific site preferences like temperature regime and edaphic attributes.

The altitudinal range is from ~1,371 to 2,743 m (a.s.l), with tree limits varying markedly with aspect and configuration. The transition from moist to dry is gradual, and many forests are intermediate, between the two (transitional/ecotone). It is considered that the abundance of tall shrub *Parrotiopsis jacquemontiana* marks the transition from the moist to the dry type, where *Artemisia brevifolia* tends to replace grass with distinctive

grayish foliage (Parker, 1924). The moist temperate forests lie between 2,000 and 2,700 m and are located in the same geographical region (N 34° 38.38' latitudes and E 73° 33.11' longitudes). At ~1,800 m, the tropical pine (*Pinus roxburgii*) forest ends, giving way to a belt of moist temperate forests followed by the subalpine *Krummholz* formation, above which alpine vegetation takes over until the beginning of the permanent snowline (Arnfield, 2023).

## 2.2. Selection of sites

The study area was subdivided into two major forest zones based on physiognomy and environmental conditions along an elevation gradient. These forest types are designated as lower

Western Himalayan temperate forests, which include (a) low-level blue pine (*Pinus wallichiana*) forests (2,000 m a.s.l.), (b) mid-level moist deodar (*Cedrus deodara*) forests (2,200 m a.s.l.), and (c) upper West Himalayan fir (*Abies pindrow*) forests (2,400 m a.s.l.). After repeated surveys, study sites were marked within each forest located in the Kaghan Valley. Low-level blue pine forest at Paprung (N 34° 37.511', E 73° 18.311'), mid-level moist deodar forest at Kamal Ban (N 34° 42. 034', E 73° 31. 232'), and upper Himalayan mixed fir forests at Naran (N 34° 55. 003') were chosen for investigation. The chosen forests encompass a broad range of altitudes, from the lower close forest (2,000–2,200 m a.s.l) to the upper timberline forest (2,400–2,700 m a.s.l) with a relatively open canopy. The three forests selected during the survey exhibited contrasting environmental conditions. In addition, natural disturbances such as fire, insect infestations, and avalanches are relatively infrequent, as they have been protected from human interference. Nevertheless, illegal collection of litter and grazing by livestock had taken place at most of the sites. The exact magnitude of this influence is difficult to estimate.

### 2.3. Vegetation sampling

Based on elevation, physiognomy, and principal plant species, the coniferous forest was stratified into the blue pine zone (200 m), the cedar zone (2,200 m), and the *Abies* zone (2,400 m). Fieldwork was carried out from mid-July to mid-August, a time of highest cover for most flowering species. Vegetation sampling was conducted during the peak growing season, July–August 2021–2022. Sampling sites were visited regularly throughout the growing season to sample flowering individuals for identification. Vegetation data were obtained from three forest types, with two sites in each forest [the difference in altitude between the upper and lower sites was ~100 m (Figure 4)].

Two sites (200 m) and three stands with an interval distance of 100 m were positioned in each forest type. In each stand, four quadrates were sampled. Three topographic positions and eight sampling stands (10 × 10 m) positioned perpendicular to the base of the slope minimized altitude and soil variations within each stand (Figure 4). A total of 144 stands were monitored. The stands were geo-referenced using GPS technology and listed. A total of 288 quadrates were sampled from 144 stands. The size of quadrate was 1 × 1 m<sup>2</sup> for herbs, 5 × 5 m<sup>2</sup> for shrubs and 10 × 10 m<sup>2</sup> for trees. Quantitative phytosociological techniques were used to record each species' density, frequency, and cover. The soil and the presence/absence of herbs and shrubs rooted in the 4 × 4 m quadrate were recorded and identified in the field. Voucher specimens of critical species were collected and identified later by matching the specimens in the Bokhari Memorial Herbarium, BZ University, Multan, Pakistan. Identifications and nomenclature were mainly based on the Flora of Pakistan (Nasir and Ali, 1972).

### 2.4. Soil sampling

Soil samples (0–15 cm) were randomly collected from each stand at three points and mixed into a composite sample. Pieces

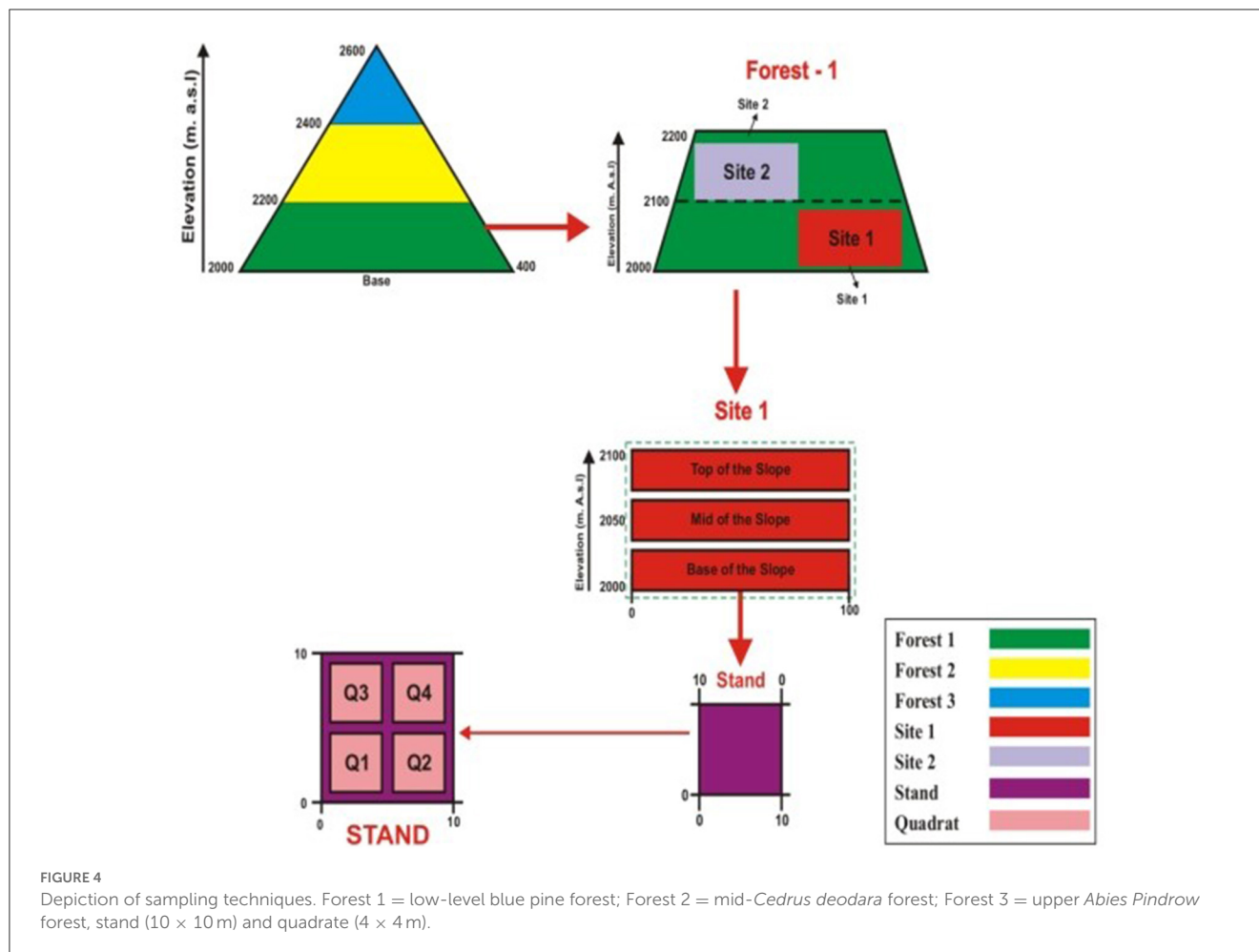
of roots, stones, and plant debris, if any, were carefully removed by sieving through a 2-mm mesh. Three subsamples were drawn from this composite sample. The collected 144 samples were oven dried at 105°C for 48 h before analysis. Soil pH was determined in 1 M CaCl<sub>2</sub> (7 gm of soil in 0.35 ml) using an HM Digital 10 K pH meter (Allen, 1989; Cramer, 2012). Soil electrical conductivity (EC) was measured on a water extract (7 gm of soil in 0.35 ml) using a CM-30 ET digital EC meter (Cramer, 2012). Soil organic matter (OM) was determined in 1 g of milled soil following the method of Walkley and Black (1934). Available phosphorus (AP) was determined following the Bray II method. Total nitrogen (TN) content was determined using the Kjeldahl method [BUCHI Kjeldahl Line B-324 (Cramer, 2012)], and the concentrations of exchangeable cations were analyzed after extraction with 1 N ammonium acetate at pH 7. Total sodium (TNa) and total potassium (TK) were measured using a flame photometer (Jenway - 500 701- 230 V). Mg<sup>++</sup> and Ca<sup>++</sup> were determined using an atomic absorption spectrophotometer, Model- GD-320 N. CO<sup>-3</sup> and HCO<sup>-3</sup> were measured using the titration method (Richards, 1954). Ordinal scales assessed the percentage rock cover, litter cover, and canopy openness. The point scale for rock cover ranged from 1 to 4, with 1 = (<75%), 2 = (25–75%), 3 = (>25%), and 4 = absence of rocks or stones. Point scales for litter cover per stand were 1–4, with 1 = (25%), 2 = (25–50%), 3 = (51–75%), and 4 = (>75%). The point scales for forest canopy openness structure also ranged from 1 to 3, with 1 = separated, 2 = side by side, and 3 = overlapped (Suarez et al., 2004).

### 2.5. Environmental data

We used several environmental variables as explanatory variables that are important for shaping the plant communities in a complex mountain landscape based on previous studies (Hall and Swaine, 1976; Tanner et al., 1992, 1998; Dasti and Angew, 1994; Herbert and Fownes, 1995; Reich et al., 1996; Vitousek and Farrington, 1997; Dasti et al., 2007; Wazir et al., 2008; Saima et al., 2009). Stands were geo-referenced (Supplementary Table S1) using the GPS Navigator (Garmin e Trex Legend H, Lenexa, Kansas). Climatic parameters such as temperature (°C), relative humidity (%), heat index (°C), and wind speed (m/s) were recorded at the time of sampling by using Kestral, Japan (4500NV Applied Ballistics Meter). The annual data for all the climatic variables were obtained from the Pakistan Metrological Department.

### 2.6. Statistical analysis

We used cluster analyses to classify the sampling units based on their similarity. Presence-absence data were used for this analysis using the default option “Farthest neighbor,” incorporating the Pearson coefficient. Ordination analyses were conducted to visualize the floristic pattern of vegetation composition in relation to environmental factors. The main emphasis was on classification ordination, which was used in part to check whether the classification results adequately reflect the main floristically gradient in the data set and to detect the relation between



some environmental factors and the composition and structure of vegetation. Species and stand data were ordinated using detrended correspondence analysis (DCA) using the program DECORANA (Dasti and Angew, 1994; Wazir et al., 2008). Ordination axes 1 and 2 were used for data interpretation; scatters of the classification groups from both procedures were plotted on overlays of the ordination to assess the compatibility of the two methods of data simplification (Dasti and Angew, 1994; Wazir et al., 2008). The relationships between altitude, soil characteristics, and DCA axes were determined using the Pearson correlation (Saima et al., 2009). The calculations were made with the help of statistical computer software (MVSP Version 3.1 and MINITAB, Version 15.0). The variation between soil heterogeneity and plant communities was estimated using variance analyses (ANOVA). Duncan multiple range tests were used to detect and compare any significant difference between the means of soil parameters in different communities at the 5% significance level.

### 3. Results

#### 3.1. Floristic structure and species diversity

A total of 154 plant species belonging to 50 families and 131 genera were recorded. Asteraceae (14), Lamiaceae (12),

Rosaceae (09 species), Fabaceae (08 species), Ranunculaceae (06 species), and Polygonaceae (05 species) were found to be the dominant families in these forests (Table 1). The remaining families were represented by less than three genera and three species and thus contributed little to the floristic richness.

#### 3.2. Vegetation structure and composition

Based on the numerical classification, six vegetation types were identified in Himalayan moist temperate forests: *Senecio chrysanthemoides* – *Clinopodium piperitum*; *Artemisia brevifolia* – *Fragaria nubicola*; *Parrotiopsis jacquemontiana* – *Indigofera gerardiana*; *Micromeria* – *Viburnum grandiflorum*; *Silene viscosa* – *Arisaema propinquum*; and *Adiantum venustum* – *Ajuga parviflora* (Table 2). The indicator values for each association are shown in Table 3.

##### 3.2.1. Association A. *Senecio chrysanthemoides* – *Clinopodium piperitum* (Group I)

This association is generally found between 2,500 and 2,600 m (a.s.l.) on the mountain slopes, which receive ~800 mm of

TABLE 2 Normal cluster analysis (NCA) of six recognized vegetation associations.

Associations	Name of association	Plot no.	Altitude (m a.s.l.)	Forest type/habitat
A	<i>Senecio chrysanthemoides</i> – <i>Clinopodium piperitum</i>	121–144	2,500–2,600	Upper <i>Abies pindrow</i> forest, upper slopes
B	<i>Artemisia brevifolia</i> – <i>Fragaria nubicola</i>	97–120	2,400–2,500	Upper <i>Abies pindrow</i> forest, lower slopes
C	<i>Parrotiopsis jacquemontiana</i> – <i>Indigofera gerardiana</i>	73–96	2,300–2,400	Mid- <i>Cedrus deodara</i> forest, upper slopes
D	<i>Micromeria</i> – <i>Viburnum grandiflorum</i>	49–72	2,200–2,300	Mid- <i>Cedrus deodara</i> forest, mid slopes
E	<i>Silene viscosa</i> – <i>Arisaema propinquum</i> .	25–48	2,100–2,200	Low-level <i>Pinus wallichiana</i> forests, lower slopes
F	<i>Adiantum venustum</i> – <i>Ajuga parviflora</i>	01–24	2,000–2,100	Low-level <i>Pinus wallichiana</i> forests, foot slopes

Each plant association has 24 stands (n =24). m a.s.l., meter above sea level.

TABLE 3 Indicator values of six plant associations.

Association	A	B	C	D	E	F
Species name	2,500–2,700	2,400–2,500	2,300–2,400	2,200–2,300	2,100–2,200	2,000–2,100
<i>Senecio -Chrysanthemoides</i>	<b>24</b>	•	•	•	•	•
<i>Dryopteris remosa</i>	19	13	5	16	15	17
<i>Clinopodium piperitum</i>	17	•	•	•	•	•
<i>Viola biflora</i>	15	17	4	16	13	17
<i>Plectranthus rugosus</i>	12	•	•	•	•	•
<i>Ligularia amplexicaulis</i>	8	•	•	•	•	•
<i>Artemisia brevifolia</i>	•	<b>24</b>	•	•	•	•
<i>Fragaria nubicola</i>	•	20	8	20	17	18
<i>Myosotis alpestris</i>	10	<b>16</b>	4	14	10	7
<i>Parrotiopsis jacquemontiana</i>	•	•	<b>24</b>	•	•	•
<i>Indigofera gerardiana</i>	•	•	<b>18</b>	16	2	4
<i>Sambucus wightiana</i>	•	1	15	12	6	13
<i>Astragalus grahamianus</i>	•	•	<b>9</b>	•	•	•
<i>Pilea scripta</i>	•	•	<b>9</b>	•	•	•
<i>Micromeria biflora</i>	1	•	1	<b>20</b>	16	16
<i>Viburnum grandiflorum</i>	•	•	5	<b>18</b>	17	17
<i>Trifolium repens</i>	6	2	11	<b>16</b>	4	7
<i>Polygonum hydropiper</i>	4	12	10	<b>16</b>	5	11
<i>Adiantum venustum</i>	8	14	•	<b>14</b>	13	18
<i>Delphinium roylei</i>	•	•	•	<b>11</b>	•	•
<i>Geranium wallichiana</i>	11	13	9	14	<b>19</b>	19
<i>Hedera nepalensis</i>	5	10	•	•	<b>11</b>	16
<i>Silene viscosa</i>	•	•	•	•	<b>9</b>	•
<i>Arisaema propinquum</i>	•	•	•	•	<b>8</b>	•
<i>Pimpinella diversifolia</i>	•	•	•	•	•	<b>3</b>

Bold values indicating dominant and distinct species.

average annual rainfall. The dominant *Senecio chrysanthemoides* and *Clinopodium piperitum* are perennial herbs. *Spiraea canescens*, *Rosa microphylla*, *Rubus biflorus*, *Lonicera quinquelocularis*, and *Jasminum humile* are important shrubs. Various ferns such as

*Dryopteris remosa*, *Athyrium rupicola*, and *Adiantum venustum* are among the first to develop in late spring after the snow melts. The important climbers include *Clematis montana* and *Hedera nepalensis* (Table 3).

### 3.2.2. Association B. *Artemisia brevifolia* – *Fragaria nubicola* (Group II)

This association colony occupies the altitudinal range between 2,400 and 2,500 m (a.s.l.) and is distinctive in the combination of a high coverage of strongly aromatic, shrubby *Artemisia brevifolia* and procumbent, white-flowered *Fragaria nubicola* along with erect, shiny blue-flowered *Myosotus alpestris*. The former species dominate the open, dry stony, while the latter is widely distributed in forests and shrubberies. The dominance of the species can be ranked in the order *Artemisia brevifolia* > *Fragaria nubicola* > *Myosotus alpestris* (Table 3).

### 3.2.3. Association C. *Parrotiopsis jacquemontiana* – *Indigofera gerardiana* (Group III)

This association occurs at an altitude range of 2,300–2,400 m (a.s.l.), and the diagnostic species of this association is *Parrotiopsis jacquemontiana*. The abundance of this species marks the transition from moist to dry forests, where *Artemisia* tends to dominate. The dominance of *Indigofera gerardiana* and *Sambucus wightiana* and the presence of *Sorbaria tomentosa* and *Spiraea vacciniifolia* indicate an ample moisture regime in this vegetation type (Table 3).

### 3.2.4. Association D. *Micromeria* – *Viburnum grandiflorum* (Group IV)

The component species of this association is distributed over the altitudinal ranges of 2,100–2,200 m (a.s.l.), corresponding to the lower part of the altitudinal range of *Cedrus deodara*. The dominant species of this association are *Viburnum grandiflorum*, *Micromeria biflora*, and blue-flowered *Delphinium roylei*. Among the component shrubs, *Viburnum grandiflorum* and *Indigofera gerardiana* are most common on stony pavements with shallow soils. *Aster falconeri*, *Geranium lucidum*, and *Trifolium repens* are common herbs found on the level of gently sloping wet meadows and pastures (Table 3).

### 3.2.5. Association E. *Silene viscosa* – *Arisaema propinquum* (Group V)

This association occupies the wetland sites of the valley highlands ranging from 2,200 to 2,300 m (a.s.l.) and is characterized by small white-flowered *Silene viscosa* and *Arisaema propinquum*. *Geranium wallichianum* assumes the leading role in the flora dominating the association. Among the shrubs, *Barbaris lyceum*, *Indigofera gerardiana*, and *Viburnum grandiflorum* contributes the most to this association. Among the ferns, *Dryopteris remosa* and *Adiantum venustum* occupy the micro-relives distributed along the wet, stony slopes. Among the component species, *Fragaria indica*, *Geranium wallichiana*, and *Micromeria biflora* are dominant on lower slopes, and *Silene viscosa* and *Viola biflora* are frequent on mid-slopes. At the same time, *Viburnum grandiflorum* is recorded at its maximum at the top of the slopes (Table 3).

TABLE 4 Pearson correlation coefficient between DCA axis scores of soil parameters and altitudes of three forest types (located along the altitudinal range 2,000–2,700-m a.s.l.).

Parameters	Coefficient axis 1	Coefficient axis 2
Altitude	0.673***	−0.486***
pH	−0.257**	0.051 NS
Electrical conductivity dS/m	−0.580***	0.324***
Organic matter %	−0.009 NS	0.043 NS
Nitrogen ppm	−0.731***	0.268**
Potassium ppm	−0.412***	0.312***
Calcium ppm	−0.431 ***	0.349***
Magnesium ppm	−0.358***	0.310***
Sodium ppm	−0.686***	0.380***
Chloride ppm	−0.159*	0.311***
Carbonates ppm	−0.385***	0.294***
Bicarbonates ppm	−0.432***	0.18**
Relative humidity %	0.077 NS	−0.048 NS
Heat index °C	−0.177 N	−0.020 NS
Average temperature °C	−0.195 NS	0.313 NS
Rainfall mm	−0.400***	0.587***
Winter snowfall cm	−0.748***	0.077***
Rock cover %	0.619***	−0.406***
Wind speed m/s	0.461***	−0.703***
Litter cover %	0.619***	−0.406***
Canopy openness	0.619***	−0.406***

\*NS, non-significant, \*\*, significant, \*\*\*, highly significant.

All the observed parameters are significant at a *p*-value of <0.001.

### 3.2.6. Association F. *Adiantum venustum* – *Ajuga parviflora* (Group VI)

This association is distributed in the low-level blue pine forest zone from 2,000 to 2,100 m (a.s.l.) and is characterized by *Pimpinella diversifolia* and *Pteracanthus urticifolia*, which were altogether absent from the rest of the study area. *Adiantum venustum*, *Ajuga parviflora*, and *Geranium tuberaria* are the conspicuous species, while *Primula rosea* and *Sambucus wightiana* are significantly frequent. Among shrubs, *Indigofera gerardiana*, *Lavatera kashimiriana*, and *Lonicera quinquelocularis* contribute sufficiently to community composition (Table 3).

## 3.3. Environmental determinants

In addition to the overriding importance of altitude in determining species distribution and shaping plant communities in mountain landscapes, most of the edaphic factors included have significant correlations with the first axis (Table 4). The importance of soil EC, K, Ca, Mg, Na, and N was notable. All these cations were negatively correlated with DCA axis 1 but were mostly much lower in values except EC, Na, and P,



TABLE 5 The mean values and standard deviation for all the soil variables for identified six associations.

Variables	Associations (m a.s.l.)						D
	A	B	C	D	E	F	
	(2,500–2,700)	2,400–2,500	2,300–2,400	2,200–2,300	2,100–2,200	2,000–2,100	
Soil pH	6.10 <sup>a</sup>	6.59 <sup>c</sup>	6.34 <sup>b</sup>	6.42 <sup>b</sup>	6.13 <sup>a</sup>	6.69 <sup>d</sup>	0.14 <sup>***</sup>
	0.09	0.57	0.27	0.20	0.10	0.42	
Soil EC (dS/m)	1.33 <sup>a</sup>	2.15 <sup>c</sup>	1.80 <sup>b</sup>	2.69 <sup>d</sup>	2.08 <sup>c</sup>	2.69 <sup>d</sup>	0.13 <sup>***</sup>
	0.13	0.33	0.58	0.12	0.25	0.06	
Organic matter %	2.31 <sup>b</sup>	2.59 <sup>c</sup>	2.45 <sup>b</sup>	2.40 <sup>b</sup>	2.51 <sup>c</sup>	2.05 <sup>a</sup>	0.14 <sup>***</sup>
	0.37	0.33	0.38	0.46	0.28	0.05	
Nitrogen ppm	0.13 <sup>a</sup>	0.14 <sup>a</sup>	0.12 <sup>a</sup>	0.17 <sup>a</sup>	0.12 <sup>a</sup>	0.23 <sup>c</sup>	0.05 <sup>***</sup>
	0.00	0.02	0.00	0.15	0.00	0.28	
Phosphorus ppm	19.35 <sup>a</sup>	24.13 <sup>c</sup>	23.34 <sup>b</sup>	23.65 <sup>b</sup>	23.42 <sup>b</sup>	25.91 <sup>d</sup>	0.43 <sup>***</sup>
	1.23	0.82	0.78	0.68	1.03	1.16	
Potassium ppm	1.17 <sup>a</sup>	1.60 <sup>c</sup>	1.31 <sup>b</sup>	1.61 <sup>c</sup>	1.32 <sup>b</sup>	1.73 <sup>c</sup>	0.24 <sup>***</sup>
	0.04	0.26	0.14	0.24	0.16	0.09	
Calcium ppm	0.25 <sup>a</sup>	0.49 <sup>d</sup>	0.35 <sup>b</sup>	0.40 <sup>c</sup>	0.39 <sup>b</sup>	0.52 <sup>d</sup>	0.04 <sup>***</sup>
	0.04	0.09	0.12	0.16	0.02	0.06	
Magnesium ppm	0.16 <sup>a</sup>	0.22 <sup>c</sup>	0.19 <sup>b</sup>	0.22 <sup>c</sup>	0.18 <sup>b</sup>	0.26 <sup>d</sup>	0.01 <sup>***</sup>
	0.02	0.03	0.02	0.02	0.03	0.03	
Sodium ppm	0.31 <sup>a</sup>	5.30 <sup>b</sup>	5.64 <sup>b</sup>	8.89 <sup>c</sup>	9.08 <sup>c</sup>	11.57 <sup>d</sup>	0.98 <sup>***</sup>
	0.07	3.24	3.61	1.51	1.62	0.84	
Chloride ppm	0.38 <sup>a</sup>	0.40 <sup>a</sup>	0.37 <sup>a</sup>	0.41 <sup>b</sup>	0.36 <sup>a</sup>	0.55 <sup>c</sup>	0.02 <sup>***</sup>
	0.03	0.05	0.05	0.06	0.07	0.05	
Carbonates ppm	2.01 <sup>a</sup>	2.40 <sup>a</sup>	2.78 <sup>a</sup>	3.26 <sup>b</sup>	3.49 <sup>c</sup>	4.63 <sup>d</sup>	0.42 <sup>***</sup>
	0.84	1.13	1.12	1.15	0.86	0.33	
Bicarbonates ppm	11.38 <sup>a</sup>	11.38 <sup>a</sup>	34.65 <sup>b</sup>	36.78 <sup>b</sup>	30.00 <sup>b</sup>	62.21 <sup>c</sup>	7.43 <sup>***</sup>
	1.35	1.35	21.94	31.51	7.91	11.25	
Relative humidity %	45.51 <sup>b</sup>	65.96 <sup>c</sup>	46.92 <sup>b</sup>	48.09 <sup>b</sup>	31.08 <sup>a</sup>	44.30 <sup>b</sup>	5.29 <sup>***</sup>
	10.72	4.65	16.98	19.57	3.41	5.34	
Heat index °C	20.77 <sup>b</sup>	15.00 <sup>a</sup>	24.29 <sup>c</sup>	21.18 <sup>b</sup>	30.37 <sup>d</sup>	21.97 <sup>b</sup>	2.51 <sup>***</sup>
	2.64	2.85	8.76	8.15	5.03	2.57	

m a.s.l., meter above sea level; \*\*\*, highly significant; *d*, Duncan value. Superscript alphabets indicating LSD = Least Significant Difference between the means at the required level of probability.

whose *r*- values exceeded 0.4. Regarding axis 2, the *r*-values of these factors were considerably low ( $r < 0.3$ ). Most of the soil cations and soil EC exhibited a positive correlation, with axis 2 suggesting cation-rich soil conditions from the top to the bottom of the gradient. All chemical variables measured in the soil samples showed broad variations at the landscape scale (Tables 4, 5). There was a general increase in the concentration of all the solutes in the sequence from the upper *Abies pindrow* forest to the mid-*Cedrus deodara* forest to the low-level *Pinus wallichiana* forest.

### 3.4. Ordination

To identify a minimal set of geo-climatic variables and to know the relative importance of these factors, stands and species ordination (DCA) was performed, using geo-climatic parameters as response variables. The DECORANA (DCA) ordination results were used to plot the scatters of classificatory results, as shown in Figures 5, 6. DECORANA (axes 1 and 2) showed a plot of 144 stands from three forest types. Stands are plotted individually, and zones are shown where

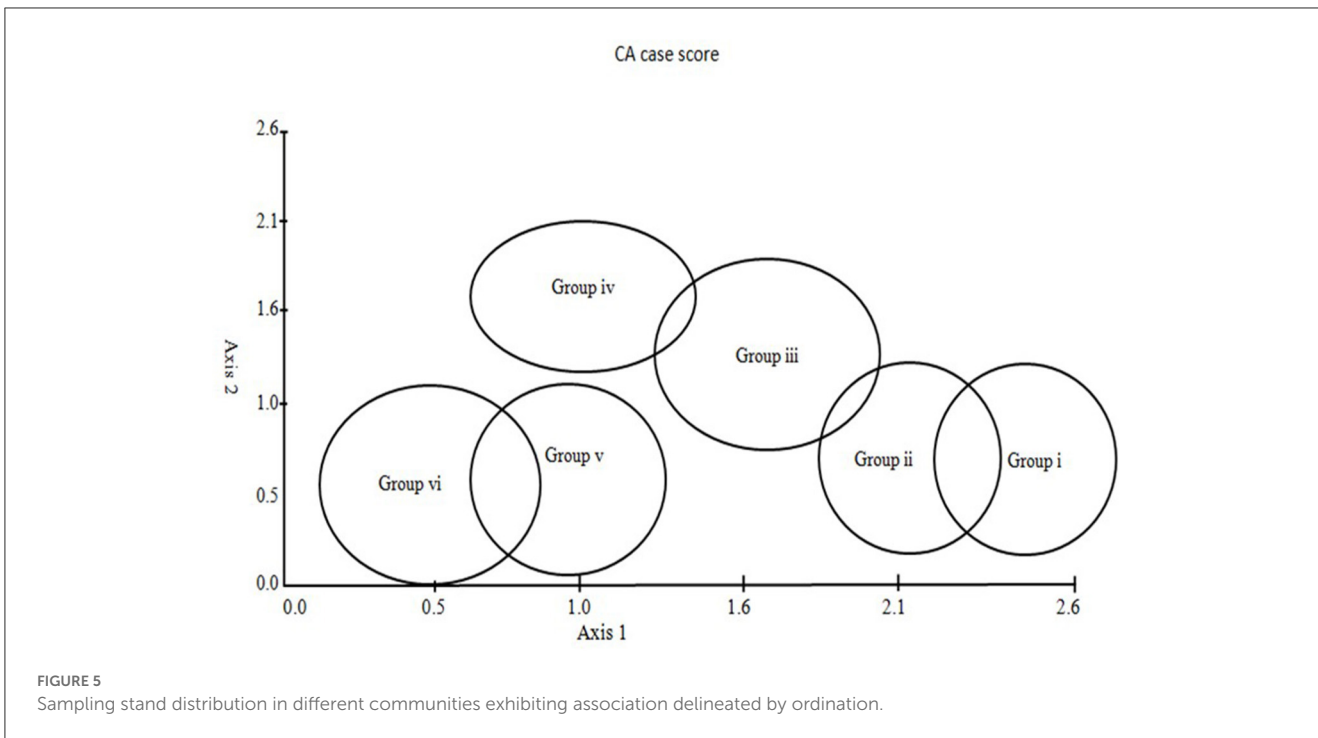


FIGURE 5 Sampling stand distribution in different communities exhibiting association delineated by ordination.

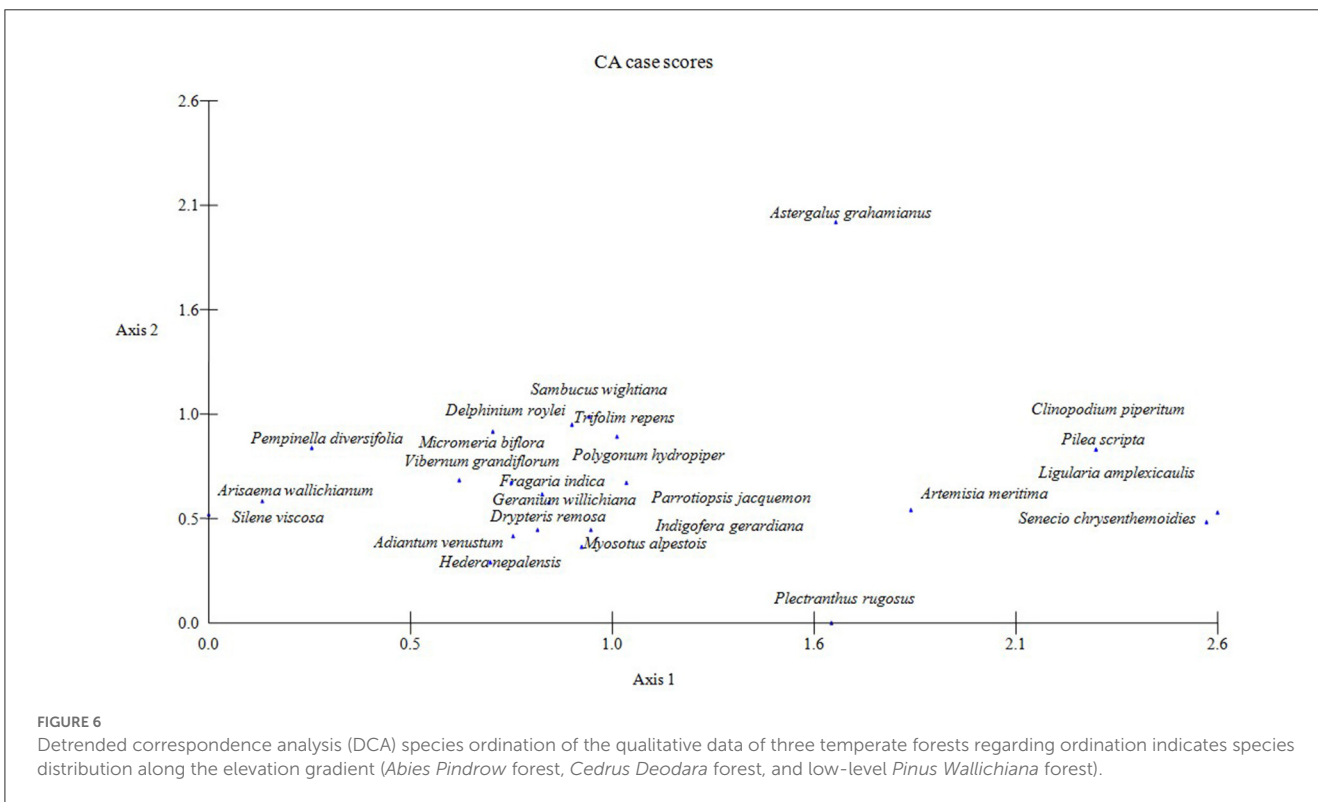


FIGURE 6 Detrended correspondence analysis (DCA) species ordination of the qualitative data of three temperate forests regarding ordination indicates species distribution along the elevation gradient (*Abies Pindrow* forest, *Cedrus Deodara* forest, and low-level *Pinus Wallichiana* forest).

the NCA segregates each of the six associations, as indicated in Figure 5. The eigenvalues of axes 1 and 2 were very large compared to the lower-order axis, and the latter were ignored (Figure 6).

### 3.5. Correlation of the ordination axes

The stands belonging to associations (A and B) delineated from the upper *Abies pindrow* forest were grouped at one end (high

scores) and those of low-level *Pinus wallichiana* forest (associations E and F) on the other end (low scores) of the DCA axis 1. Stands belonging to the associations C and D identified in the mid-*Cedrus deodara* forest occupy the intermediate position along axis 1, reflecting the mid-elevations of the study area (Figure 5). The results depicted in Figure 6 confirm the overlapping nature of the associations in space defined by the ordination axes. The first ordination axis represents an elevation gradient, with the highest elevation on the right (high scores) and the lowest on the left (low scores). Within the first axes, species such as *Senecio chrysanthemoides*, *Ligularia amplexicaulis*, *Clinopodium piperitum*, and *Artemisia brevifolia* lie at the most elevated end of axis 1. At the same time, *Pimpinella diversifolia*, *Arisaema propinquum*, and *Silene viscosa* are confined to the lowest elevation end of the gradient. The diagram's midpoint is occupied by *Parrotiopsis jacquemontiana*, *Sambucus wightiana*, *Micromeria biflora*, *Trifolium repens*, and *Delphinium roylei*. Similarly, on axis 2, *Plectranthus rugosus* and *Hedera nepalensis* are at the lower end of the axis, while *Sambucus wightiana* and *Trifolium repens* are at the opposite end. The second axis represents increasing soil cations from the top to the bottom.

## 4. Discussion

Low-level *Pinus wallichiana* forest is located between 2,000 and 2,200 m (a.s.l); in this forest type, there is no definite evidence of basic changes through human activities. The forest under consideration is exclusive of blue pine with a small admixture of spruce (*Picea smithiana*), deodar (*Cedrus Deodara*), and fir (*Abies Pindrow*). The top canopy is more or less continuous. The mid-level moist deodar (*Cedrus deodara*) forest is nearly pure, but some spruce is also present in patches. Deodar extends into the inner drier ranges of the Himalayas, ultimately becoming sufficiently different to be described as dry deodar. Upper-west Himalayan fir and mixed broad-leaved forest represent the subalpine forests where regeneration of *Abies pindrow* is usually fairly abundant. The general climate of this forest is dry and temperate; however, soil moisture is adequate, which makes it difficult to distinguish it from most temperate forests.

The extensive growth of *Artemisia brevifolia* distinguishes the upper fir forests from the lower coniferous belt. Champion et al. (1965) and Hussain and Illahi (1991) described these forest types completely. The temperature, relative humidity, and wind speed were significantly related to DCA axes 1 and 2. Both the ordination axes are significantly influenced by altitude and the environmental queues generated by it, which indicated some important implications for these factors in determining vegetation attributes. For example, low species richness in associations belonging to upper forests may be attributed to increasingly strong winds, reduced precipitation, reduced temperature, increased soil acidity, and a reduced supply of nutrients with increasing altitude. These results confirm those of Pendry (1994).

Soil pH usually falls with altitude, and the most acidic soils are generally found in upper fir forests. These findings are consistent with those of Pendry and Proctor (1996) but contradict the results of Veneklaas (1991), who reported a higher pH of soils in upper forests than soils in nearby lower forests. Soil organic matter increased with altitude, partly because of reduced

decomposition at lower temperatures but often due to temporary waterlogged conditions created by melting snow in the upper mountains. Extractable phosphorus is also low at higher altitudes. The elevational reduction in phosphorus might be partially due to a high concentration of organic matter, which reduced the potential of phosphorus fixation (Tanner et al., 1998). Differences in the concentration of cations among the three forests are noted. These differences may be largely attributed to the parent material (Pendry and Proctor, 1996), but the importance of the downslope movement of water cannot be ignored (Dasti et al., 2007, 2010; Wazir et al., 2008). The study demonstrates significant associations between the landscape-level patterns of environmental heterogeneity and the distribution patterns of plant communities and species across mountain landscapes. Two factors seem to be significant: altitude and substrate. The overriding importance of altitude as an environmental factor affecting plant species association is not surprising, considering its close correlation with temperature and rainfall (Danin et al., 1975; Dasti and Malik, 1998; Dasti et al., 2007; Wazir et al., 2008; Saima et al., 2009). The analysis and assessment of patterns and the zonation along the first axis suggest that the most important environmental gradients and boundaries across the landscape are associated with the downslope movement of water, soil chemistry, and organic matter. It is difficult to assess the relative importance of these factors in comparison with altitude. Still, the consistent negative interaction terms between these factors suggest that some combined effect is significant. The reasons for these correlations might be due to variations in runoff patterns.

The spatial distribution of soil moisture might correlate with rainfall in lower blue pine valleys, which receive an appreciable amount of runoff. However, the situation is quite different in the upper rocky mountains with patches of soil. Here, soil moisture distribution depends on the ratio of rock surface to soil volume (Olsvig-Whittaker et al., 1983; Dasti and Malik, 1998; Wazir et al., 2008). These patterns seem best explained by interactions between soil depth and the downslope redistribution of runoff. The lower forests gain water from run-on, while the upper forests lose water from run-off. This run-off will be distributed along a moisture gradient, along which vegetation change will be gradual. Besides this factor, snow accumulation and its gradual melting are of considerable importance in determining the vegetation type at high elevations. Apart from the differences in moisture regime, the topographically induced variation in soil EC plays a significant role in community composition and plant assemblage.

The species belonging to associations located at lower elevations occur on soil with relatively high EC, which decreases with an increase in altitude. Thus, the altitudinal floristic differences may partially be attributed to soil EC. The decrease in EC with increased altitude is largely due to the downward movement of nutrients, which affects spatial distribution along the altitudinal transect (Pendry and Proctor, 1996; Dasti and Malik, 1998; Raja et al., 2014). The correlation of soil pH with the distribution and association of plant species is not surprising but has already been reported in several studies (Pendry and Proctor, 1996). We have demonstrated that the topographically induced edaphic patchiness governs the distribution of the species across the landscape. A clear relationship between the characteristics of the substrate and associations defined by numerical analysis

shows that these groupings of plant species are not arbitrary assemblages.

Differences in soil within the forest are distinct enough to favor different species at different locations and thus create numerous floristically differentiated forest patches. These findings confirm the edaphic patchiness model rather than the random walk or regional homogeneity model (Tuomisto et al., 2003). In this respect, the spatial pattern of environmental conditions along the elevation gradient appears particularly important to plant communities' composition and distribution. Altitude and topography govern the properties of the soil, which are of overriding importance in determining the variations in floristic composition. Sharp species turnover occurs when the environmental conditions change, and different (dominant) species are found at sites with different environmental conditions. These findings are consistent with the findings of Lieberman et al. (1985) and Clark et al. (1998, 1999). The dominance of only one plant species at most sites was obvious in the field, and this is a notable feature of the vegetation of Himalayan moist temperate forests. However, a few associations, defined by cluster analysis and confirmed by DCA, showed that some species were restricted to the upper forests and others to the low or mid forests. Still, several have distribution ranges that extend into all associations.

The visual representation of the results resemble the continuous nature of the vegetation more than the grouping produced by classification. However, describing the salient features of associations between stands and species with ordination is easy and worthwhile. The scatters of the DCA demonstrate the overlapping rather than discrete boundaries between the vegetation types and species distributions. This overlapping nature of the vegetation types might be due to the species overlapping environmental preferences. The substrate of all these communities is found through the interaction of topography and related geomorphological processes of surface movement through wind and downslope movement of water, which are expected to bring about arbitrary changes in dominance within the association. Finally, the altitude limits the vegetation observed along an altitudinal gradient. For example, the dominance of *Senecio chrysanthemoides* and *Clinopodium piperitum* is restricted to high altitudes (2,400–2,700 m a.s.l). These species were absent from altitudes below 2,400 m a.s.l. Similarly, the species dominating the low forest (*Silene viscosa* and *Arisaema propinquum*) were not found in the upper fir forest zone.

## 5. Conclusion

The present study described the vegetation patterns and community composition in three different forest zones along the altitudinal gradient. Our findings revealed that these forest types significantly differ physiognomically and structurally. The special nature of the mountain landscape, with its variable altitude and topographically induced environmental variations, is the main factor that determines the prominent vegetation zones in these mountain forests. The soil's physical and chemical properties appear to be the most highly influential factors in the distribution and diversity of species along the altitude. The present investigation showed that the distribution of community

types, species composition, and diversity are better understood by studying geo-climatic factors along the elevational gradient on the mountain landscape. Based on the comprehensive botanical survey and early descriptive accounts of the study area, the vegetation in the temperate forest zone was stratified into three physiognomic units: (a) low-level *Pinus wallichiana* forest, (b) mid-*Cedrus deodara* forest, and (c) upper *Abies pindrow* forest. As Himalayan moist temperate forests exhibit a rather stable floristic composition and slow species dynamics, the different years in which the vegetation was sampled were not considered a serious methodological problem.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

## Author contributions

MH, EB, AD, MK, TF, and AAb contributed to the study's concept, design, and statistical analysis. MK, SM, MH, AAs, and AD contributed to the analysis and interpretation of the data. EB, MK, and HA contributed to the investigation and resources. MH, AAb, HA, and ZA contributed to the drafting of the manuscript. SM, EB, TF, AAs, MK, and AD contributed to this manuscript's review, editing, and proofreading. HA contributed to funding acquisition and study supervision. All authors contributed to the article and approved the submitted version.

## Funding

This research was funded by the Researchers Supporting Project number (RSP2023R123), King Saud University, Riyadh, Saudi Arabia.

## Acknowledgments

We would like to extend our sincere appreciation to the Researchers Supporting Project number (RSP2023R123), King Saud University, Riyadh, Saudi Arabia.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/ffgc.2023.1195491/full#supplementary-material>

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