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Spatiotemporal Distribution Patterns of Climbers along an Abiotic Gradient in Jhelum District, Punjab, Pakistan

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Abstract: Climber–abiotic parameter interactions can have important ramifications for ecosystem's functions and community dynamics, but the extent to which these abiotic factors influence the spatial distributions of climber communities in the western Himalayas is unknown. The purpose of this study was to examine the taxonomic diversity, richness, and distribution patterns of climbers in relation to abiotic variables in the Jhelum District. The data were collected from 120 random transects between 2019 and 2021, from 360 sites within triplet quadrats (1080 quadrats), and classification and ordination analyses were used to categorize the sample transects. A total of 38 climber species belonging to 25 genera and 11 families were recorded from the study area. The Convolvulaceae were the dominant family (26.32%), followed by the Apocynaceae (21.05%), and Leguminosae (15.79%). The majority of the climbers were herbaceous in nature (71.05%), followed by woody (23.68%). Based on the relative density, the most dominant species was *Vicia sativa* (12.74). The majority of the species flowered during the months of March–April (28.04%), followed by August–September (26.31%). Abiotic factors have a significant influence on the distribution pattern and structure of climbers in the study area. The results show that the climbers react to the biotic environment in different ways. The findings will serve as the foundation for future botanical inventories and will be crucial for understanding the biological, ecological, and economic value of climbers in forest ecosystems. This will help forest management, conservation, and ecological restoration in the Himalayas.

Keywords: climbers; distribution patterns; ecological restoration; abiotic variables

1. Introduction

Plants that are rooted in the ground but require assistance to support their weak stems are known as climbers. They are common, particularly in all tropical forests, but are found in almost all ecosystems and actively compete with trees for light and space [1]. Climbers (woody and herbaceous) provide an important ecological and structural component in forest and early successional habitats. They function as a physical connection between the ground and the canopy layer [2,3]. Despite the obvious abundance of climbing plants in some regions, past community studies largely overlooked climbers and their ecology. Their significance in succession and other community dynamics has recently been studied more closely [4,5]. Climbers and lianas play a vital role in forest ecology, contributing to the overall plant diversity [6,7]. However, climbers contribute substantially less to the overall abundance, variety, and structure in temperate forests than they do in tropical forests [8,9]. In temperate climates, lianas are often sparse (particularly in northern North America and Europe) [6,10]. In terms of function, lianas have a variety of pollination, dispersal, and phenological systems and supply a variety of resources to animals (e.g., foliar, floral, and fruit); additionally, lianas play an important part in the preservation of biological diversity [11].

The spread of climber species throughout the landscape is influenced by the same environmental gradients that drive other types of plant development, such as rainfall, light, topography, soil moisture, seasonality, and soil fertility [12]. Environmental and host tree features vary depending on the habitat's successional stage. Climbers such as lianas and other climbers are more common in early successional environments with canopy gaps [13]. The diversity and abundance of liana species vary greatly from one forest to the next and between forest locations. Over the last two decades, researchers have focused on identifying liana abundance and distribution patterns in various ecosystems as well as understanding the underlying causes of these patterns [4,14]. Despite the lack of sufficient research, climbers and lianas (woody vines) are important forms of forest growth. However, the diversity and distribution of forest climbers and lianas around the world have been studied in several research projects, especially in Africa [1,2,6,15], in South America [7], Central America [6], and in Asia [16]. Even though climbers comprise a large percentage of the vegetation composition in the Himalayas, particularly in Pakistan, climbers have been practically disregarded in prior floristic research.

The associations of climatic and edaphic factors have significant effects that can control the vegetation types, their composition and structure, and their distribution patterns. Therefore, this influence upon the variations on the vegetation patterns in the studied district should be monitored on a regular basis to conserve the threatened species. The current research hypothesizes that the vegetation patterns of the Jhelum district are greatly influenced by a novel indigenous environment and climate and aims to discover the following objectives and unanswered questions for the very first time. With this research gap in mind, we devised the following aims for the current study: (I) to evaluate the composition, diversity, and distribution patterns of climbers in the study area; (II) to determine which group of abiotic factors determine the association pattern in the region; (III) to use a multivariate approach to examine the relationship between climbers and abiotic parameters in the region; and finally, (IV) to determine the potential factors underlying the observed patterns. Upon discovering the answers to these questions, our study will help fill a gap in the knowledge of the Himalayas and the world's mountainous areas in general. This research will have implications for forest management, conservation, and the ecological restoration of the Himalayan landscape.

2. Materials and Methods

2.1. Study Area

The Jhelum district in Pakistan is located to the north of the Jhelum River and is bordered to the north by Rawalpindi, to the south by Sargodha and Gujrat, to the east by Azad Kashmir, and to the west by Chakwal district [17,18]. The district is a semi-arid, warm, and subtropical region with hot summers and harsh winters. Jhelum is a semi-mountainous range with an average annual rainfall of 880 mm and an average temperature of 23.6 °C [19]. The Jhelum River comprises about 98,800 ha of plains and another 16,500 ha of hilly terrain (Figure 1). Jhelum is home to the world's 2nd largest salt mine (Khewra), which occupies about 900 ha. People in the Jhelum district have a broad range of life experiences, cultures, customs, and beliefs and have long used local plants for a variety of purposes [20,21].

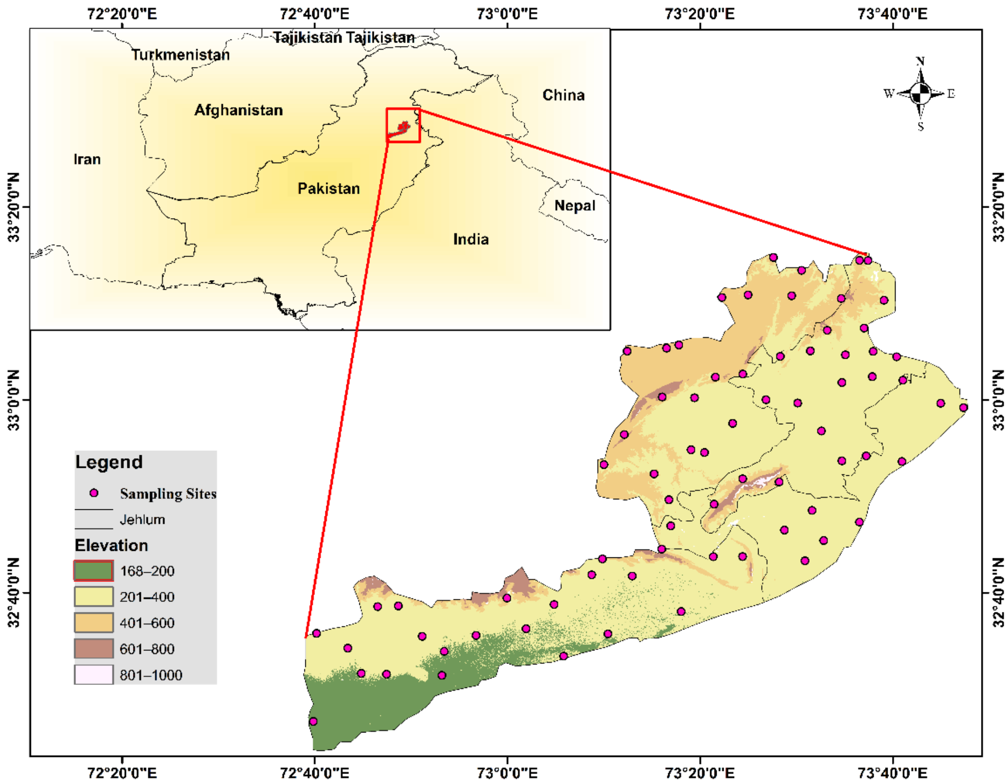

Figure 1. Map of Jhelum district displaying the sampling sites [17].

2.2. Fieldwork

A comprehensive field survey was carried out from 2019 to 2021, exploring the botanical diversity of Jhelum. Plants were collected and photographed during the field survey. Flora of Pakistan (http://www.efloras.org, accessed on 6 May 2021) and other sources of floristic literature were used to determine the species in the region [22,23]. The collected plant specimens were marked with voucher numbers, pressed, properly dried, and mounted on international standard-sized herbarium sheets and preserved at the Department of Botany, University of Gujrat, Punjab, Pakistan. The currently accepted binomials of each plant species, as well as the family names, follow the plant list ver. 1.1 (http://www.theplantlist.org, accessed on 11 March 2021) (TPL, 2013), as proposed by Majeed et al. [20] and Khan et al. [22], after the initial identification of specimens.

2.3. Plant Sampling

Ecological data for climbers were collected by the transect method. A total of 120 transects of 1 hectare (100 m^2) were laid randomly throughout the study area. Five quadrats of 20 m^2 each for climbers and host trees were systematically set in each transect [1,3,14,24]. Elevation and coordinates of each transect were measured using a Garmin e Trex [25]. Moreover, the slope and aspects of each transect were measured using a compass. In each quadrat, the density of climbers and host plants was calculated [1,26].

2.4. Soil Sampling

From each transect, three soil samples were collected randomly (0–30 cm). The collected samples were then merged to create a composite sample, which was then stored in polythene bags and labeled for laboratory analysis. A digital pH meter was used to determine electrical conductivity (EC) and pH from soil water extracts. The organic matter was determined using the Walkley–Black method [27], which was further refined by [28], and the total nitrogen content was determined using the [27] Kjeldahl method. The contents of potassium (K) and phosphorus (P) were measured [28]. $CaCo_3$ content was determined by acid–base neutralization. Moisture content in soil samples was determined using a

ScalTec moisture analyzer set to 110 °C. The saturation percentage was estimated using the formula [28,29] given below

$$\text{Saturation} = \text{Mass of wet soil} - \text{Mass of oven dry soil} \times 100/\text{Mass of oven dry soil}.$$

2.5. Data Analysis

Plant IVI and stand-level soil data were calculated and analyzed using ordination The data from 120 transects were entered into an MS Excel spreadsheet [1,28]. Cluster analysis was used to divide climbers into groups. For cluster analysis, the specific density of each plant present in the 80 transects was used as the starting point. The optimal pruning point for the dendrogram was determined using Ward's technique. PAST software (version 4.07) was used to determine the clusters and diversity indices for each group of clusters [30–32]. The Pearson correlation between abiotic and non-biotic variables was calculated using the R program [33]. To investigate the impact of environmental gradients on species composition, the software CANOCO version 4.5 [31,34–36] was used to perform Canonical Correspondence Analysis (CCA), which was then detrended. The overall working pattern is given in Figure 2.

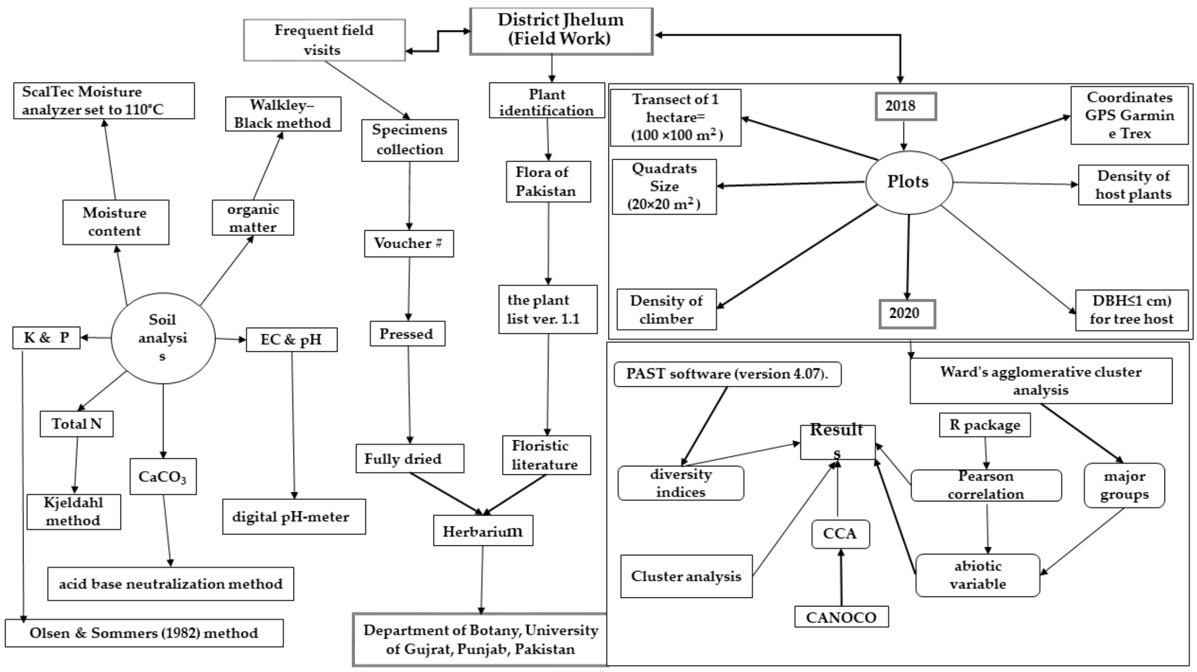

Figure 2. Jhelum district representing working progress flow sheet diagram.

3. Results and Discussion

3.1. Composition and Diversity

We found 38 climbers belonging to 25 genera and 11 families from 120 randomly selected transects (Table 1). Climbing plants significantly contribute to the overall abundance and species diversity of forests worldwide. For example, Rahman et al. [1], Carrasco-Urra, and Gianoli [26] measured the abundance of 72 climber species in the Atlantic Forest of Brazil, which varied significantly due to succession and current disturbance in the forest. Ghollasimood et al. [37] discovered 4901 climber individuals in Malaysia's Perak coastal hill forest, belonging to 45 climber species in 37 genera and 20 families.

Table 1. Taxonomic status, climbing mode, phenology and relative density of climbers in Jhelum district.

Plant Name	Family	Climbing Mode	Phenology	Relative Density			
				G1	G2	G3	G4
Asparagus officinalis L.	Asparagaceae	Scrambler	August–September	2	0	66	0
Vincetoxicum spirale (Forssk.) Meve & Liede	Apocynaceae	Twiner	March–April	36	38	166	6
Cissampelos pareira L.	Menispermaceae	Tendril	July–August	36	47	161	12
Causonis trifolia (L.) Mabb. & J. Wen	Vitaceae	Tendril	August–September	68	32	46	0
Citrullus colocynthis (L.) Schrad.	Cucurbitaceae	Scrambler	May–June	8	115	73	0
Cocculus hirsutus (L.) W. Theob.	Menispermaceae	Scrambler	July–August	0	133	60	24
Convolvulus arvensis L.	Convolvulaceae	Scrambler	March–April	24	31	81	8
Convolvulus prostratus Forssk.	Convolvulaceae	Scrambler	February–April	0	64	119	0
Cryptolepis buchananii Roem. & Schult.	Apocynaceae	Twiner	March–April	26	0	13	181
Cucumis melo L.	Cucurbitaceae	Scrambler	June–July	0	22	0	0
Cuscuta reflexa Roxb.	Convolvulaceae	Twiner	December–January	0	122	0	0
Cynanchum auriculatum Royle ex Wight	Apocynaceae	Twiner	March–April	6	12	56	20
Dioscorea deltoidea Wall. ex Griseb.	Dioscoriaceae	Twiner	August–September	0	10	3	255
Galium aparine L	Rubiaceae	Scrambler	June–July	36	21	103	0
Ipomoea alba L.	Convolvulaceae	Twiner	March–April	4	16	0	0
Ipomoea aquatica Forssk.	Convolvulaceae	Scrambler	February–April	126	42	4	0
Ipomoea cairica (L.) Sweet	Convolvulaceae	Twiner	July–August	36	3	0	0
Ipomoea nil (L.) Roth	Convolvulaceae	Twiner	May–June	32	0	0	0
Ipomoea pes-tigridis L.	Convolvulaceae	Twiner	August–September	2	24	0	0
Ipomoea purpurea (L.) Roth	Convolvulaceae	Twiner	August–September	28	0	68	160
Lantana camara L.	Verbenaceae	Scrambler	August–September	0	256	208	0
Lathyrus aphaca L.	Leguminosae	Tendril	September–October	0	218	6	0
Lathyrus sativus L	Leguminosae	Tendril	March–April	24	306	51	0
Distimake aegyptius (L.) A.R. Simoes & Staples	Convolvulaceae	Twiner	August–September	12	224	0	0
Momordica balsamina L.	Cucurbitaceae	Tendril	May–June	98	299	0	0
Mukia maderaspatana (L.) M. Roem.	Cucurbitaceae	Scrambler	August–September	0	304	0	0
Pentatropis capensis (L. f.) Bullock	Apocynaceae	Twiner	March–April	0	7	0	0
Pentatropis nivalis (J.F. Gmel.) D.V. Field & J.R.I. Wood	Apocynaceae	Twiner	July–August	0	358	0	0
Pergularia daemia (Forssk.) Chiov.	Apocynaceae	Twiner	February–April	0	216	4	0
Pergularia tomentosa L.	Apocynaceae	Twiner	February–April	0	232	2	0
Rhynchosia capitata (Roth) DC	Leguminosae	Scrambler	March–April	28	45	17	0
Rhynchosia minima (L.) DC.	Leguminosae	Scrambler	March–April	40	93	81	0
Smilax aspera L.	Smilacaceae	Hook climber	August–September	102	193	26	184
Tinospora sinensis (Lour.) Merr.	Menispermaceae	Woody Climber	April–May	0	0	16	251
Trichosanthes dioica Roxb.	Cucurbitaceae	Tendril	July–September	0	27	97	0
Vincetoxicum hirsutum (Wall.) Kuntze	Apocynaceae	Twiner	March–April	0	18	0	212
Vicia bakeri Ali	Leguminosae	Scrambler	August–September	0	0	42	0
Vicia sativa L.	Leguminosae	Scrambler	March–April	128	207	283	0

In Nigerian secondary woods, Muoghalu and Okeesan [38] found 49 climber species, comprising 35 lianas and 14 vines and spanning 41 genera and 28 families; additionally, they found 53 climber species in Lambir, Malaysia. However, because of their erratic growth patterns and the difficulty of field identification, the climbers' ecology lags far behind that of other vascular plant groups. Our findings are in line with previous research, and they give us the chance to document 38 climber species in Pakistan's Himalayan region to fill a gap in our knowledge about the area.

The dominant family was Convolvulaceae (26.32%), followed by Apocynaceae (21.05%), Leguminosae (15.79%), Cucurbitaceae (13.16%), Menispermaceae (7.89%), Dioscoriaceae, Asparagaceae, Smilacaceae, Rubiaceae, Verbenaceae, and Vitaceae (2.63%). The majority of the climbers were herbaceous in nature (71.05%), followed by woody (23.68%), parasitic, and climbing shrubs (2.63% each). *Ipomoea* (15.78%) was the most dominant genus, followed by *Lathyrus*, *Vicia*, *Rhynchosia*, *Convolvulus*, *Pentatropis*, and *Pergularia* (5.26%), each with identified species. According to Muthumperumal and Parthasarathy [39], the family composition of the dominating climber species varies across the tropics, despite the stability of the family structure at the continental level. Apocynaceae, Leguminosae, Annonaceae, Combretaceae, Loganiaceae, and Rutaceae are generally the most common climbers in Asian tropical forests. In the current study, Apocynaceae and Leguminosae were also the dominant families in the Jhelum district.

3.2. Functional Traits

Most species possessed twiner mechanisms for climbing (42.1%), followed by scrambling (36.84%), tendrils (15.78%), and hook climbers (2.63%). Similar to previous studies, stem twiners were the most common climber type (42.1%) in this study [4,14,39–41]. In our study, scramblers represented 36.84% and tendrils 15.78% of the total climbers in the area. The mean relative density indicated that the most dominant species was *Vicia sativa* (12.74), followed by *Lantana camara* (9.84), *Momordica balsamina* (9.35), *Lathyrus sativus* (8.64), *Pentatropis nivalis* (8.58), *Smilax aspera* (8.54), *Distimake aegyptius* (6.40) and *Mukia maderaspatana* (6.24). *Ipomoea nil*, *Ipomoea pes-tigridis*, *Ipomoea alba*, and *Pentatropis capensis* were rare species in Jhelum. In the current study, the density and richness of the climber species decreased with elevation in the district of Jhelum. This is in contrast to the findings of Rahman et al. [1], who recorded a high density and species richness in the Murree Hill Forest at a high elevation. According to Rahman et al. [1], low-altitude forests have a higher climber density than those at higher elevations, which is similar to our findings. The abundance and richness of the lianas increased significantly with the abiotic factors and responded differently to climate factors. Therefore, comparative studies on climbers are urgently needed to increase our understanding of climbing plants and improve their management in forests.

The majority of the climber species flowered during the months of March–April (28.04%), followed by August–September (26.31%), February–April and July–August (10.52%), May–June (7.89%), and June–July (5.26%) (as show in supplementary Table S1). This was similar to the observations made by [42] in the Pakistani Himalayas and [30,43] in the Kashmiri Himalayas in India. Haq et al. [44] reported similar findings, attributing the findings to the species' adaptation to the specific climatic patterns of each region. The plant's phenological pattern will provide important information about the peak activity of the phenological events in the plants, ultimately serving as a basis for comparisons in different conditions [45]. Climbers, on the other hand, have a different ecological role and may play an important role as indicators of changes in the weather in the future.

3.3. Classification and Ordination of Climber Plants

Using Ward's agglomerative cluster analysis (Figure 3), we classified 120 transects into four major groups. A two-way cluster analysis revealed three associations of sampling transects based on species presence and absence (1/0). As shown in the figure, the species data matrix of 120 sampling transects is clustered into three associations (Figure 4). The species richness and diversity indices for the three associations are shown in Table 2.

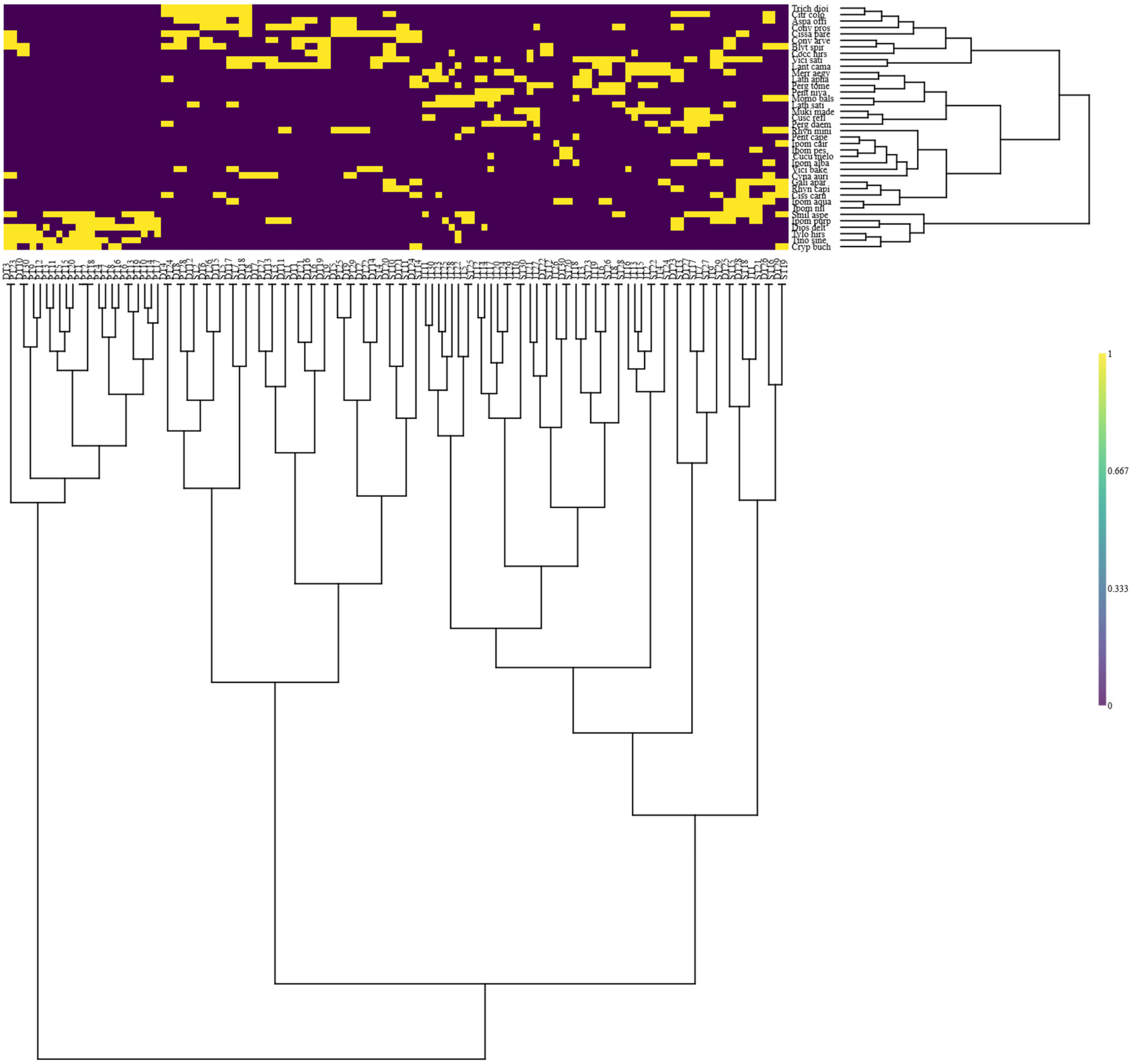

Figure 3. Two-way cluster dendrogram showing distribution of 38 species and 120 transects. Blue represents an absence while yellow represents the presence of species.

Table 2. Various diversity indices of climber in Jhelum district.

Diversity Indices	Group I	Group II	Group III	Group IV	Mean
Species Number	22	32	26	11	22.75
Dominance_D	0.08301	0.05618	0.0733	0.1539	0.091598
Simpson_1-D	0.917	0.9438	0.9267	0.8461	0.9084
Shannon_H	2.712	3.091	2.836	1.973	2.653
Evenness_e^H/S	0.6843	0.5947	0.6557	0.6541	0.6472
Brillouin	2.643	3.06	2.793	1.948	2.611
Menhinick	0.7325	0.5993	0.6042	0.3036	0.5599
Margalef	3.086	4.366	3.323	1.393	3.042

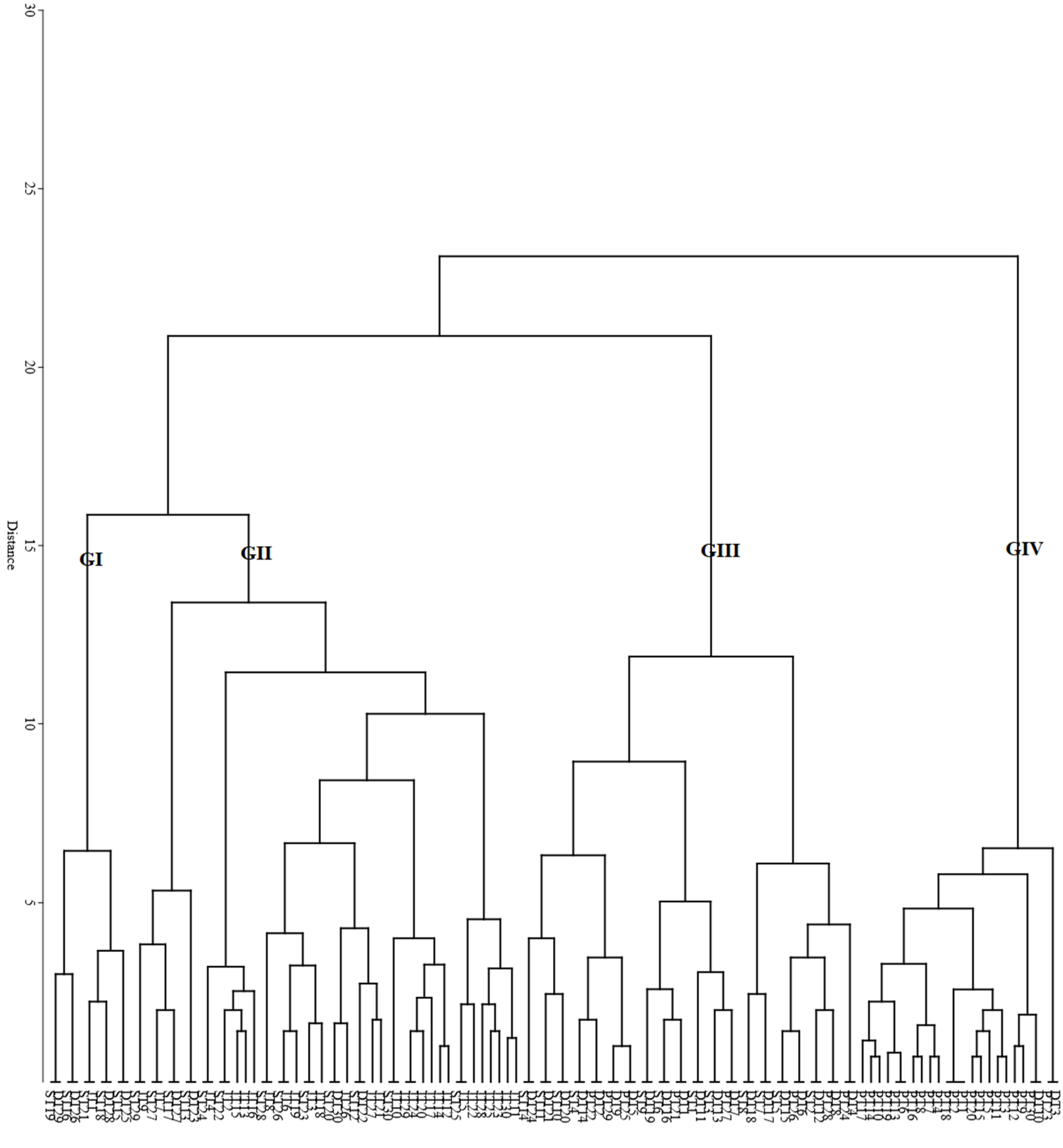

Figure 4. Cluster dendrogram showing distribution of 38 species into 4 groups.

3.3.1. Group I

This group had 10 transects with 902 individuals belonging to 22 species. With an 8.6 relative density, *Pentatropis nivalis* was the dominant species. *Momordica balsamina*, *Mukia maderaspatana*, *Distimake aegyptius*, and *Lathyrus sativus* were the other most abundant species. Group I had a 0.65 species richness and a 0.56 species evenness, and its Simpson and Shannon's diversities were 0.93 and 2.88, respectively.

3.3.2. Group II

Group II had 52 sampling transects with 3812 individuals belonging to 37 species. The most dominant species in association 2 was *Vicia sativa* with a 7.0 relative density, followed by *Lantana camara* with 5.1, *Cissampelos pareira* with 4.9, and *Vincetoxicum spirale* with a 4.2 relative density. Other notable species in Group II were *Convolvulus arvensis*, *Ipomoea aquatica*, and *Rhynchosia minima.* Group II had a 0.76 species richness and a 0.72 species evenness, while its Simpson and Shannon's diversities were 0.94 and 3.08, respectively.

3.3.3. Group III

Group III included only 35 sampling transects with 1852 individuals from 26 species. The most dominant species in association 3 was *Dioscorea deltoidea,* with an 11.5 relative density. *Tinospora sinensis* and *Vincetoxicum hirsutum* were two of the most common species in group III; they had relative densities of 11.3% and 8.2%. Group III had a species richness of 0.31 and a species evenness of 0.6, while its Simpson and Shannon's diversities were 0.85 and 2.34, respectively (Table 3). Similar findings were made by [46], who said that the region had the right mix of biotic and abiotic factors to support a wide variety of species.

Table 3. Summary of DCA analysis.

Axes	1	2	3	4	Total Inertia
Eigenvalues	0.746	0.538	0.389	0.249	6.207
Lengths of gradient	4.827	4.317	5.136	2.924	
Cumulative percentage variance of species data	12	20.7	27	31	

3.3.4. Group IV

Group IV included only 23 sampling transects with 1313 individuals from 11 species. The most dominant species in group IV was *Tinospora sinensis*, with a 10.5 relative density. In group IV, *Smilax aspera* had a relative density of 9.3, and *Ipomoea purpurea* had a relative density of 7.2. The species richness and evenness were the highest (0.61 and 0.58, respectively) in group 3. The diversity of the Simpson and Shannon diversities were 0.74 and 2.02, respectively.

The complexity and function of a community can be calculated using species diversity. The highest Simpson and Shannon diversity indices were calculated for Group IV, which indicates that species diversity is negatively correlated with elevation. The species richness of a region is influenced by a variety of environmental factors such as geography, terrain, species pool, area productivity, and species competition. The highest species richness index was recorded for Group IV, which was found at low elevations (Table 4). While the Simpson and Shannon's diversities were 0.83 and 1.9, respectively, the transects in group III were mostly at high elevations compared to the other two associations, which were at low altitudes.

3.4. DCA Ordination of Climbers

A DCA dispersed diagram of species (based on the species score) indicated the position of the different species along the two axes and their association with the gradients (Figure 5). On the extreme upper left side of the DCA diagram, the species *Cucumis melo*, *Pentatropis nivalis*, *Pergularia daemia*, *Cucumus maderaspatana*, *Merremia aegyptia*, and *Cuscuta reflexa* possessed a low score on axis 1 and a high score on axis 2. These species prefer dry habitats at low elevations. The upper-right side of the diagram included *Smilax aspera*, *Dioscorea deltoidea*, *Vincetoxicum hirsutum*, *Tinospora sinensis,* and *Cryptolepis buchananii,* with a high score on axis 1 and axis 2. These high scores reveal this species' preference for generally dry and slightly cold environments found at high elevations. These species were separated by a small distance, indicating the microclimatic variations in the area. The species *Asparagus officinalis*, *Trichosanthes dioica*, *Vicia bakeri*, *Citrullus colocynthis,* and *Convolvulus prostrates* on the lower left side indicate that these species prefer a xeric environment. The species *Vicia sativa*, *Lantana camara*, *Ipomoea alba*, *Ipomoea aquatica*, *Cocculus hirsutus*, *Ipomoea nil*, *Causonis trifolia Rhynchosia minima*, and *Convolvulus arvensis*, which are in the middle of the diagram, show that these species do not seem to have a preference for certain habitats and are found in many different types of environments.

Table 4. Summary of CCA analysis.

Summary					
Axes	**1**	**2**	**3**	**4**	**Total Inertia**
Eigenvalues	0.599	0.161	0.109	0.092	6.207
Species–environment correlations	0.912	0.668	0.675	0.672	
Cumulative percentage variance of species data:	9.7	12.3	14	15.5	
Cumulative percentage of species-environment relation:	46.3	58.8	67.2	74.3	
Sum of all eigenvalues					6.207
Sum of all canonical eigenvalues					1.294
Summary of Monte Carlo test					
Test of significance of first canonical axis: eigenvalue = 0.599 F-ratio = 7.159 p-value = 0.0020 Test of significance of all canonical axes Trace = 1.294 F-ratio = 1.471 p-value = 0.0020					

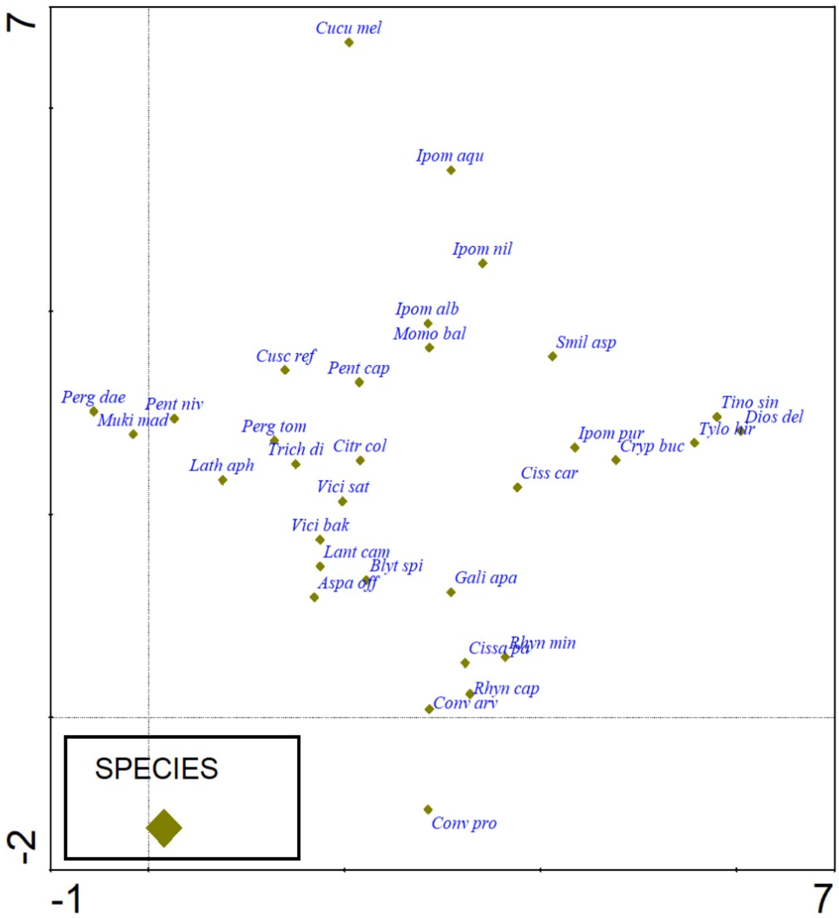

Figure 5. DCA showing the distribution of climber species.

The DCA diagram of the 120 transects yielded two vegetation zones. Zone 1, at a low elevation, included the first and second association transects, while association three was at high elevations (Figure 6). The DCA ordination for the 38 species and 80 transects showed a maximum gradient length for axis 1 of 4.827 with an Eigenvalue of 0.746. Axis 2 had a gradient length of 4.317 and an Eigenvalue of 0538. The climber plants had a total inertia of 6.207 (Table 3). Similar grouping strategies were employed by [47,48] to identify vegetation based on indicator species.

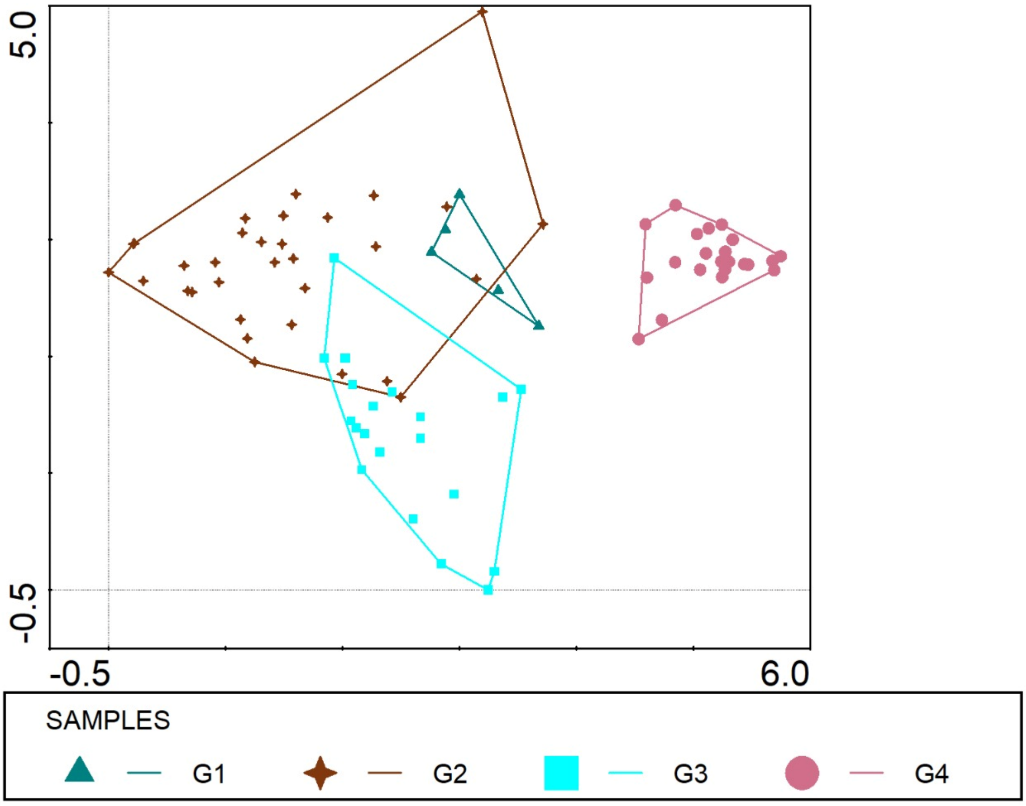

Figure 6. DCA shows the distribution of transect.

3.5. Role of Abiotic Variables on Species Distribution

The results of the CCA stand-ordination differed significantly from those of the DCA. For the most part, the transects fell on the lower left side of the CCA diagram. Of the analyzed abiotic variables, the slope; slope aspect; altitude; soil moisture; soil pH; soil saturation; the contents of calcium carbonate ($CaCO_3$), potassium (K), phosphorus (P), and nitrogen (N); and the organic matter percentage showed clear impacts. Climbers in the first quadrat of the CCA were affected by the soil electrical conductance, soil pH, and altitude. This quadrat's species included *Tinospora sinensis*, *Vincetoxicum hirsutum*, *Dioscorea deltoidea*, *Cryptolepis buchananii*, and *Smilax aspera*. In the second quadrat, the climbers were under the influence of calcium carbonate ($CaCO_3$) and nitrogen (N), and this quadrant's species included *Cocculus hirsutus*, *Ipomoea purpurea*, *Ipomoea cairicaa*, *Pergularia tomentosa*, *Convolvulus arvensis*, *Convolvulus prostratus*, *and Vincetoxicum spirale*. In (Figures 7 and 8), we show that the climbers in the 4th quadrat are affected by saturation, aspect, and organic matter. Whereas *Vicia bakeri*, *Galium aparine*, and *Lantana camara* are all in this quadrat.

The species composition and richness in group 4 were greatly influenced by the slope, aspect, altitude, phosphorus content, soil organic matter, and soil pH. The species pattern changed according to fluctuations in the abiotic variables. The plants in group 1 and 2 were under the control of soil moisture and the nitrogen content percentage in the soil, while the plants in group 3 were influenced by all the abiotic variables due to their cosmopolitan nature.

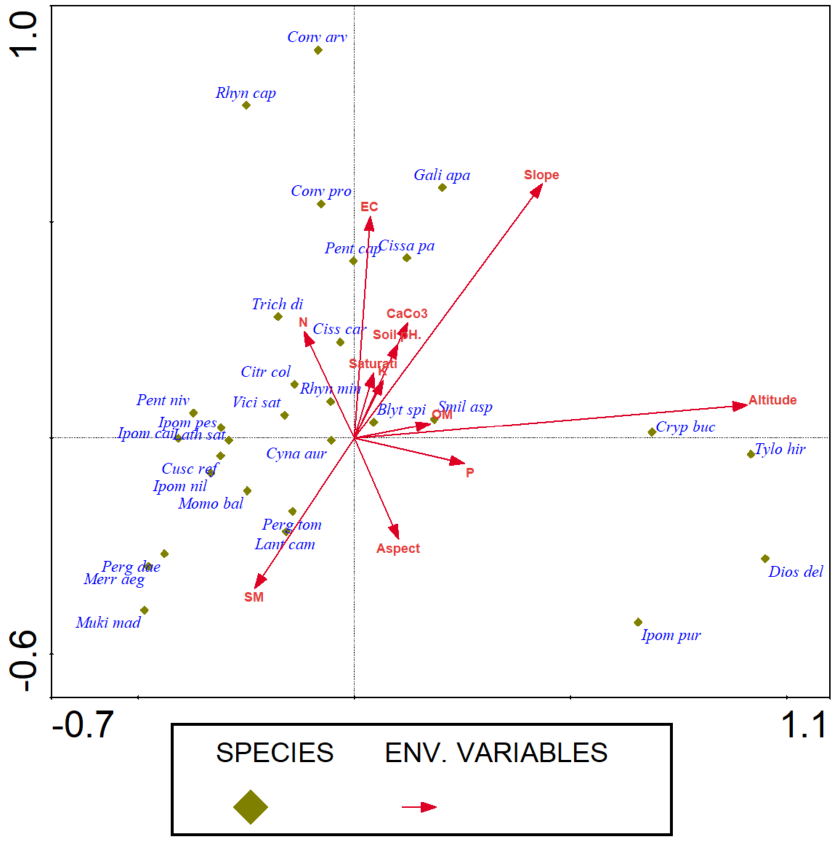

Figure 7. CCA biplot diagram of climber species and abiotic variables.

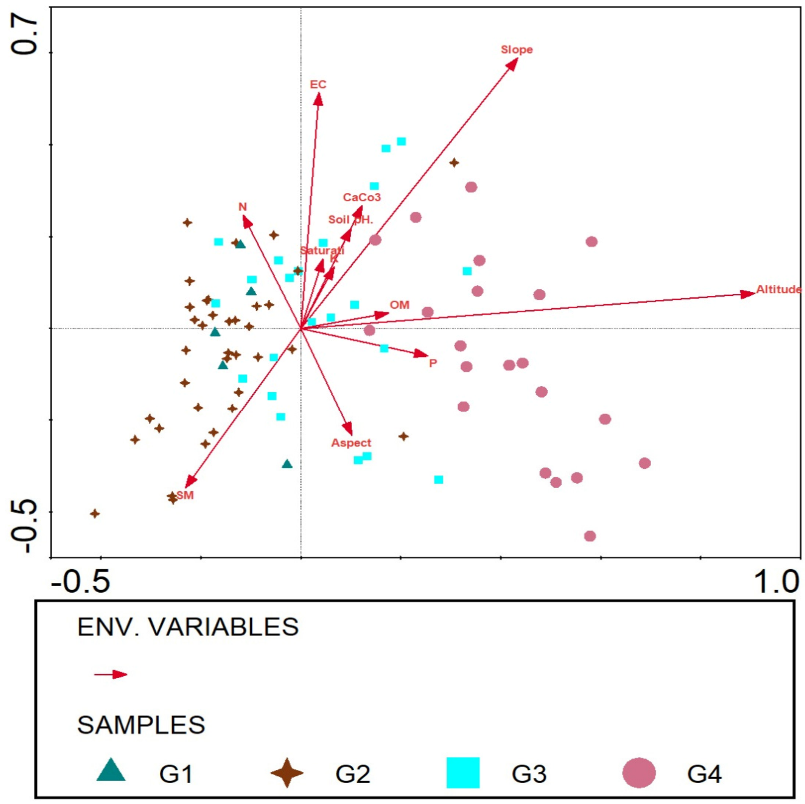

Figure 8. CCA bi-plot diagram of transect and abiotic variables.

The first CCA axis accounted for 9.8 of the variance, while the second axis explained 12.3. The third and fourth axes of the CCA explained 14–15.5 of the accumulative variance in the climber data, suggesting that soil moisture and aspect had the strongest links with the third and fourth axes, which could have a significant impact on the distribution pattern of the climber species. Based on the CCA results, several species were common at all elevations, and only a few unique species emerged at specific elevations (Table 4).

The Pearson correlation was calculated for the 12 abiotic variables (Figure 9), such as the slope aspect, altitude, slope, soil pH, EC (dS^{m-1}), AV. P (ppm), CaCO3 (%), soil moisture (%), SP (%), N (%), AV. K (ppm), and organic matter (%) (Supplementary Table S2). The species diversity, richness, and distribution of the climbers were found to be influenced most by altitudinal variation, slope, slope aspect, and abiotic gradients. Even on a small spatial scale and within a narrow altitudinal range, the altitude appeared to be the most important environmental factor, having a negative relationship with climbers' diversity and abundance. The climbers were also found to prefer places with a high soil moisture, a high nitrogen content, a low pH, and a low altitude demand for growth. Our findings are corroborated by [49], who attributed the climbers' diversity and abundance to their hosts and elevation. This was similar to other studies that found lianas in abundance at lower altitudes [1,6,8,29,50]. Abiotic variables have been involved in influencing the spread of lianas in habitats in other research works [3,6,15,32,40]. While working, Liu et al. [51] reported similar findings, attributing the distribution, community structure, and abundance of the climbing species to environmental conditions such as soil nutrients. Further research must be conducted on climbers in the forest ecosystems of the Himalayan region.

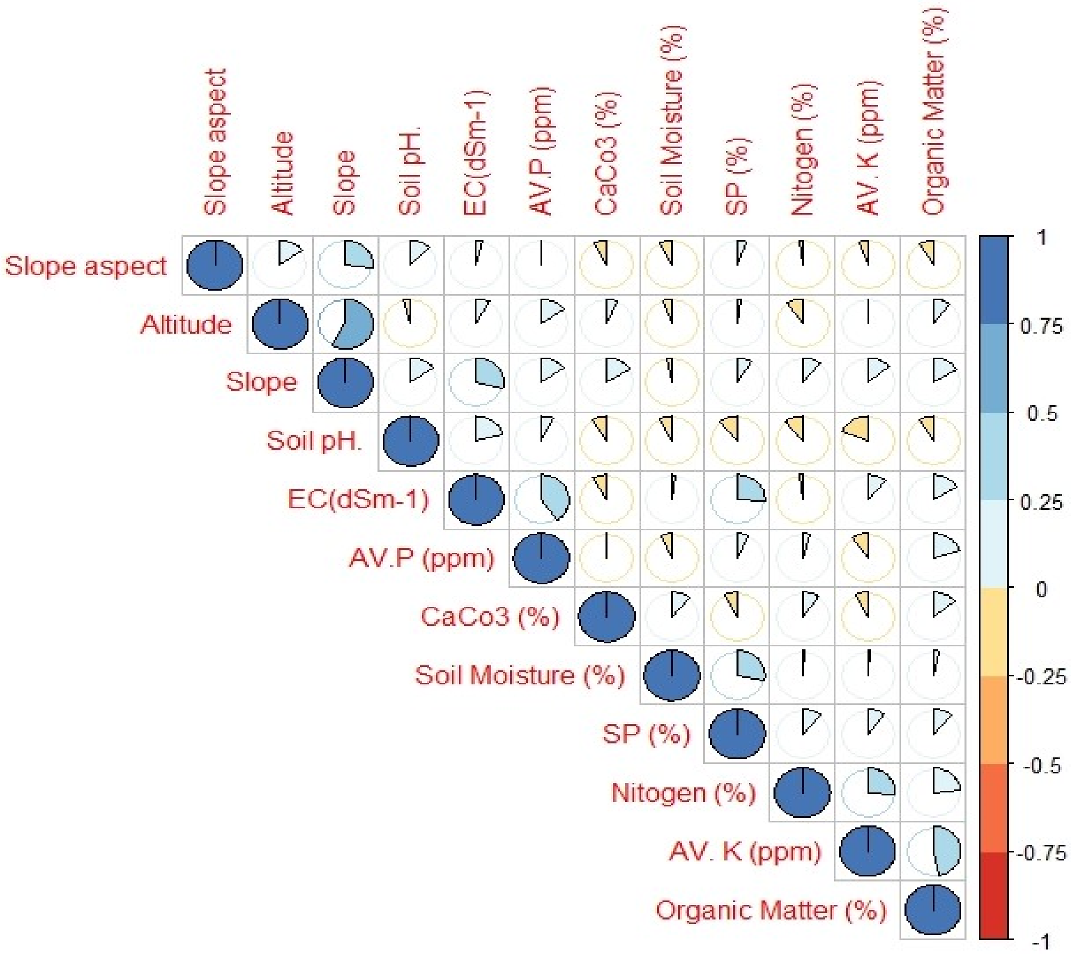

Figure 9. Pearson correlation among the various abiotic variables.

4. Conclusions

According to the results of our study, Jhelum harbors a diverse range of climbers, contributing to the overall floral diversity of the region. The most dominant family was Convolvulaceae (26.32%), followed by Apocynaceae (21.05%). *Vicia sativa* (12.74) was the most dominant species, followed by *Lantana camara* (9.84). Herbaceous climbers comprised the majority of the climbers (71.05%), followed by woody climbers (23.68%). The recorded twiners were (42.1%), following by scrambling (36.84%), tendrils (15.78%), and hook climbers (2.63%). Overall, 12 abiotic variables were studied: slope aspect, altitude, slope, soil pH, soil moisture (%), EC (dS^{m-1}), CaCO3 (%), SP (%), N (%), AV. P (ppm), AV. K (ppm), and organic matter (%). The species diversity, richness, and the distribution of the climbers were found to be influenced most by altitudinal variation, slope, slope aspect, and abiotic gradients. With an increasing elevation, the species diversity and richness declined, and the abiotic variables had a major impact on the assemblage and distribution pattern of climbing plants. Abiotic factors critically affected the structural composition and distribution pattern of the climbers. This study's findings serve as a basis for future botanical inventories and are critical to understanding the biological, ecological, and economic importance of climbers in forest ecosystems. Our findings will also contribute to filling a knowledge gap in Himalayan botanical studies and will have policy implications for forest habitat management, conservation, and the ecological restoration of Himalayan landscapes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13081244/s1, Table S1: Analysis of vegetation distribution patterns from District Jhelum, Punjab, Pakistan; Table S2: Analysis of Abiotic variables from study area.

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