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Ecological gradient analyses of plant associations in the Thandiani forests of the Western Himalayas, Pakistan

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Abstract: In the summers of 2012 and 2013, vegetation of Thandiani in the Western Himalayas of Pakistan was surveyed and quantified. We took evidence from relationships between 252 species and 11 measured environmental factors as well as changes in the associations' structure among 50 analysed stations with 1500 m^2 plots. We analysed how the plant associations differ and develop under the influence of their respective ecological gradients. Preliminary results showed that the family Pinaceae was the most abundant family with a family importance value (FIV) of 1892.4, followed by Rosaceae with FIV = 1478.2. Rosaceae, represented by 20 species, was the most dominant family, followed by Asteraceae and Ranunculaceae with 14 and 12 species each, respectively. Analyses via CANOCO software version 4.5 and GEO database demonstrated strong correlations among species distributions and environmental variables, i.e. elevation, topography, and edaphic factors. Our findings show an increase in species diversity and richness from lower elevation (1290 m at sea level (m asl) to higher elevation (2626 m asl). It is evident that aspect, elevation, and soil factors were the decisive variables affecting qualitative and quantitative attributes of vegetation in the study area. The P value ≤ 0.002 confirms a significant impact of abiotic factors that bring variation in vegetation. A 3D view of the study area was generated in ArcScene showing all the five plant associations. Graphs of scatter plot, point profile, and 3D line profile were added to the layout of plant association maps. The habitats of the five association types overlapped broadly but still retained their specific individuality. The execution of GIS framework gave spatial modelling, which ultimately helped in the recognition of indicator species of specific habitat or association type. These findings could further be utilised in devising the forest policy and conservation management. This study also opens new doors of research in the field of biogeography, systematics, and wildlife.

Key words: Plant associations, Ecological gradient, deterended correspondence analysis, canonical corresponding analysis, electrical conductivity, organic matter, species richness, ecological gradient, geographic information system, Thandiani forests of Himalayas, Pakistan

1. Introduction

Statistical software packages, for instance CANOCO and PCORD, are frequently used in the fields of phytosociology and phytogeography to show correlations of biotic and abiotic factors of an ecosystem in a more meaningful and scientifically interpretable way. Excursions and field surveys are the procedures ecologists are continuously using to understand vegetation compositional dynamics more effectively (Khan et al., 2012, 2016a). Forest development and dynamics are long-lasting processes that continue through seed dispersal mechanisms, environmental influences, and anthropogenic ups and downs. The relationships between vegetation and environment in Thandiani subforests division (TsFD) were strong like many other adjoining areas and researchers have analysed different aspects of vegetation structure, dynamics, and classification in different parts of Pakistan (Saima et al., 2009; Ahmad et al., 2016; Khan et al., 2016b, 2016c; Rahman et al., 2016a). This broad vegetation survey on TsFD connects field studies with the mechanisms of remote sensing for better description of landscape dynamics using robust techniques (Fagan et al., 2004; Lawrence, 2005). We mainly addressed two questions in the current study: (1) is it possible to classify vegetation of the region into different associations under the influence of environmental factors? (2) can the database technology be helpful in vegetation mapping and possible future conservation implications? The effects of elevation on the

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structure of vegetation within geo-morphological units in the study area were investigated. ArcGIS 10.2.1 (ArcScene, 3D Analyst, Spatial Analyst) was used for the analysis and mapping of the geographical position of vegetation type within the study area. In this study, vegetation dynamics of TsFD were linked to its environmental variables. Our method involves random parameterisation of the measured and estimated variables, followed by a dynamics partitioning via distance-based redundancy analysis of the vegetation structure, composition, and coordinates.

2. Materials and methods

2.1. Study area

The study area is the part of moist temperate forests of the western Himalayas of Pakistan with a comparatively rich biodiversity. The TsFD is located in the Galis forests division, Abbottabad, between 3329° to 3421° N latitude and 7255° to 7329° E longitude over an area of 24,987 ha, of which 2484 ha is Reserve Forests and 947 ha is Guzara Forests (Khan et al., 2016b). The elevation range of the mountains reaches above 2600 m above sea level (m asl) at the highest point, of which Thandi is the Thandiani top, having an elevation of 2626 m asl (Figure 1). Most of this area is covered with pine forests and may be divided into three elevation ranges, namely the top range (2200 m to 2600 m asl), medium range (1700 m to 2200 m asl), and lower range (1200 m to 1700 m asl).

2.2. Data collection

Field trips were arranged in order to collect the phytosociological data of TsFD. Eight different stands were selected on the basis of different ecological gradients. The data were collected from 50 randomly selected sites/stations at these 8 stands. For data collection the quadrat method was used following Malik and Malik (2004) and Khan et al. (2013a). Vegetation as well as ecological data was taken at various stands; each consists of 30–35 quadrats of different sizes for trees, shrubs, and herbs. Sizes of quadrats used for trees, shrubs, and herbs were 10 × 5 m, 5 × 2 m, and 0.5 × 0.5 m, respectively. Similarly, the suitable numbers of quadrats in each stand were 5, 10, and 15, respectively. A GARMIN eTrex Vista GPS was used to collect data for analyses in ArcGIS; 10.2.1. Soil was collected from a depth of 15 cm and mixed to get a composite sample for each station. Plant specimens were also collected and taken to the herbarium, Department of Botany, Hazara University, Khyber Pakhtunkhwa,

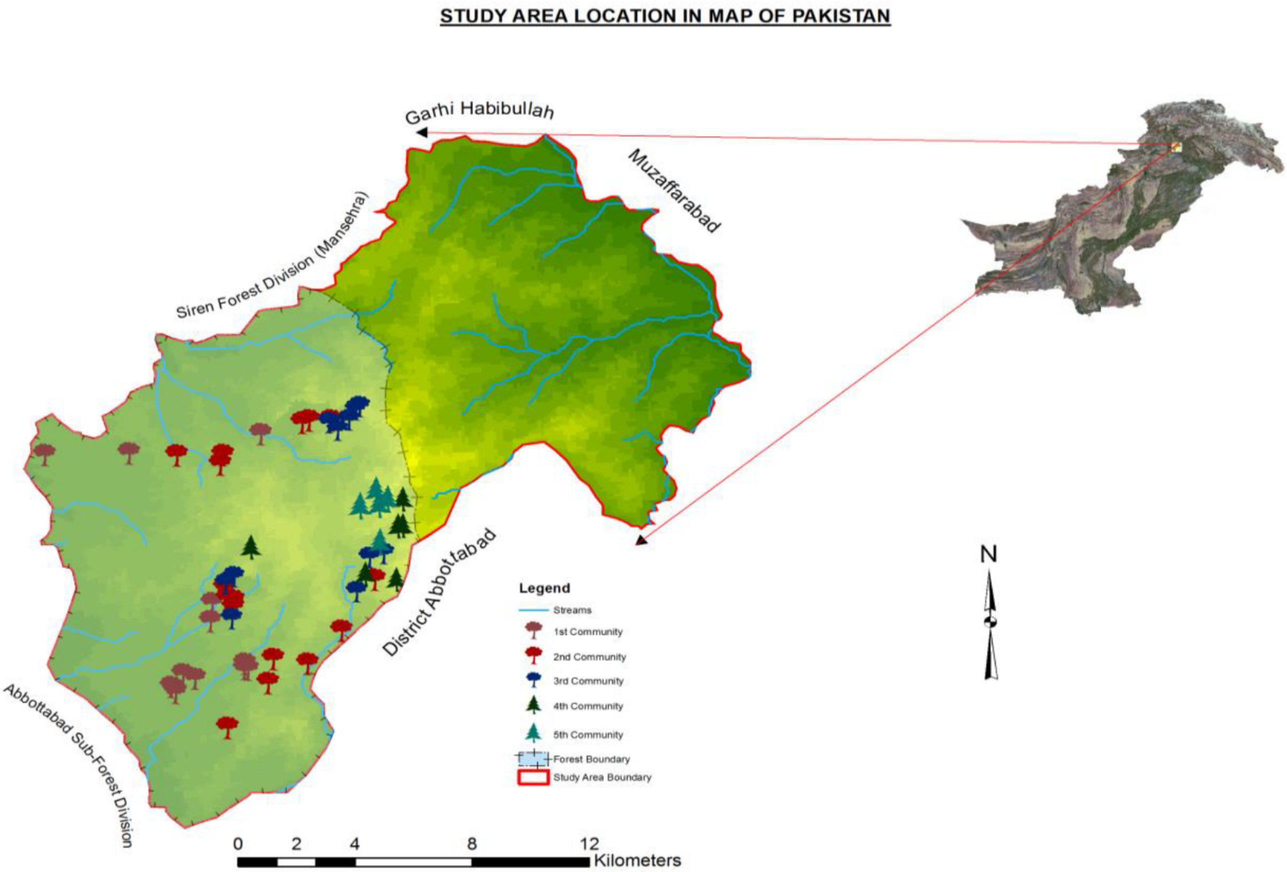

Figure 1. Map of the study area showing geographical distribution of different plant associations/communities and habitat types in the study area (Khan et al., 2016b).

Pakistan, where they were identified following Stewart (1972) and Nasir and Ali (1972).

2.3. Data analyses

Classification and ordination are two frequently used methods of multivariate statistics to obtain plant associations and their ecological gradients in an unbiased way (Siebert et al., 2002; Pavlů et al., 2003). Direct and indirect ordination techniques were used to observe the plants–environment relationship using the CANOCO program version 4.5 (Ter Braak & Smilauer, 2002; Hejcmanovā and Hejcman, 2006) after the use of PCORD version 5 (Khan et al., 2016b). Detrended correspondence analysis (DCA) was used to detect the length of the gradient and canonical correspondence analysis (CCA) was applied to draw and understand the strength of each environmental variable on quantitative attribute of the plant species and associations in the region.

The findings of CANOCO were reconfirmed using remote sensing tools and potential harmony was found between the results obtained. An amoPersonal GEO database was created in ArcGIS 10.2.1 to save all GEO datasets. A GPS receiver (GARMIN eTrex Vista) was used to record coordinates of various stations in the sampled region. Based on field data and observations, boundaries of the study site were marked with the help of Google Maps. A digital elevation model (DEM) (three arc second, i.e. x,y = 90 × 90 m) was applied to mask the study area through the spatial analyst tool in which the extraction was kept greater than the mask. Hydrology > fill tool was used to fill the masked DEM layer and to remove small imperfections in the data. ArcGIS calculates the natural breaks automatically based on which via symbology technique the classes of elevation were increased up to 30. In this way the real grouping of the values occurred in a natural way. The same data were utilised in ArcScene 10.2.1 for creation of 3D visual diagrams of various plant associations. Streams are the main types of waterbodies in the region, which were delineated using the toolset of hydrology > stream tool order and later on converted to feature class through the "stream to feature" tool. Data of different plant associations analysed via PCORD and CANOCO were fed to ArcMap via the "Excel to table" conversion toolbox (Krivoruchko, 2012). Attributes were categorised according to the type of association fed. A point map was created through overlaying of the plant association pattern on the DEM layer of the study region. Based on the Z value of each plant associations' point, graphs of the point profile were created from the 3D layer. Graphs of the scatter plot matrix for plant associations were compared with the results obtained through CANOCO software. A 3D line profile was created through elevation cross section of interpolating heights on the DEM surface. A 3D view of the study area showing all plant associations was generated in ArcScene. Graphs of scatter plot, point profile, and 3D line profile were added to the layout of plant association maps.

3. Results

3.1. Floristic diversity

Field preliminary surveys confirmed the family Pinaceae as the most abundant family with 1892.4 family importance value (abbreviated as FIV), followed by Rosaceae with 1478.2 and Ranunculaceae with 762.1. The other major families like Piplionaceae, Polygonaceae, Poaceae, Asteraceae, Plantaginaceae, and Euphorbiaceae were represented by 742.6, 689.1, 539.4, 494.1, 405.2, and 397.1 FIV, respectively (Figure 2). Based upon plant habits vegetation of the region can be classified into 51 trees (20.24%), 48 shrubs (19%), and 153 herbs (60.76%). The most abundant plant family was Rosaceae with 20 species and a share of 20.6%, followed by Asteraceae with 14 species and 14.43% share. Ranunculaceae, Papilionaceae, Apiaceae, Caprifoliacea, Labiateae, Solanaceae, and Araceae were represented by 12, 9, 6, 6, 6, 6, and 5 plant species each, respectively. The remaining families were represented by less than 5 species each (Figure 3).

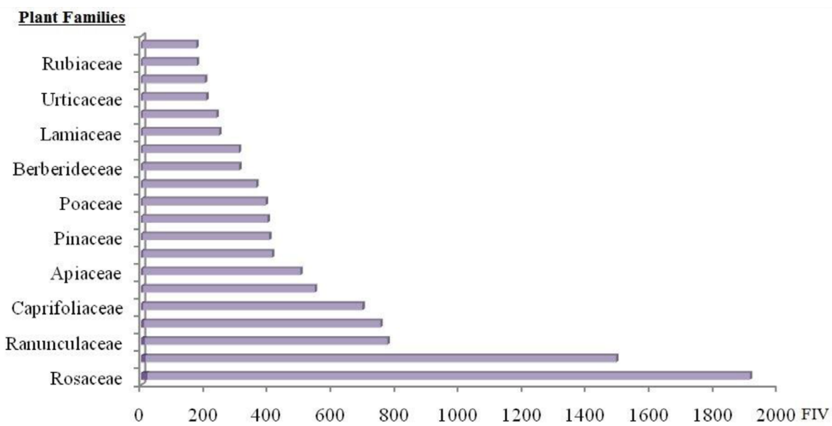

Figure 2. Plant families of TsFD having the highest family importance values (FIVs).

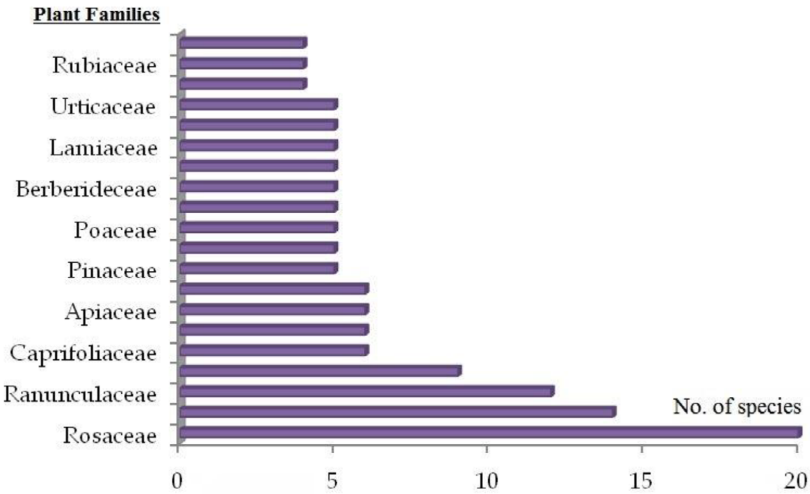

Figure 3. Graph showing most represented plant families based on number of species in the region.

3.2. Vegetation mapping and plant associations

According to elevation variation the area was divided into the following two broad regions, i.e. the lower TsFD ranging from 1299 to 1900 m asl and the upper TsFD region ranging from 1900 to 2626 m asl. The lower region represented subtropical to temperate sort of vegetation, while the upper one represented moist temperate to cool temperate type of floristic elements. The association types identified through personal GEO database and Canoco software were given names based on the respective indicator of the specific association. The whole vascular flora of the region was divided into five plant associations/habitat types.

3.2.1. Plant association of lowest elevation (1290–1591 m)

The association was found at the elevation of 1290 to 1591 m asl. The tree, shrub, and herb layers have characteristic (indicator) species of *Melia azedarach* L., *Punica florida* Salisb., and *Euphorbia helioscopia* L. The environmental variables that determined the occurrence of this association were low electrical conductivity, least organic matter, and low soil pH, which were linked with associated co-variables like aspect, phosphorous contents, and soil texture (Figures 4–7).

3.2.2. Plant association of lower elevation (1600–1900 m)

This assemblage can be observed at an elevation range of 1600 to 1900 m. The tree, shrub, and herb layer possess characteristic species of *Ziziphus jujuba* Mill., *Zanthoxylum armatum* DC., and *Rumex nepalensis* Spreng, respectively. The north-west aspect was one of the determining factor of this association since those slopes received less direct sunlight. Other main influencing environmental variables in the formation of this association were the low pH value of soil and trace amount of organic matter. Associated co-variables were lower electrical conductivity, high phosphorous contents, and sandy loam to clay loam sort of soil texture. Anthropogenic disturbances in this association included timber removal and plant collection for different purposes (Figures 4–7).

3.2.3. Plant association of middle elevation (1900–2150 m)

This association exists in the elevation ranges from 1900 to 2150 m asl. The southern aspect plays an important role in determination and differentiation of this plant association. *Quercus incana* Bartram, *Cornus macrophylla* Wall., and *Viola biflora* L. were the idiosyncratic species of this association. This plant association showed its best development in southern-east facing slopes at middle elevation range of the mountains, where vegetation was exposed to direct solar radiation due to slope orientation. The other related influencing variables were relatively high phosphorous contents in soil, slightly basic soil pH, and sandy loam textural soil. In contrast to the association 2 the pH value of soil at this association is slightly higher. The other associated co-variable was contents of organic matter, which plays a small role in the unique development of this plant association (Figures 4–7).

3.2.4. Plant association of higher elevation (2150–2400 m)

This association is formed at high elevations, 2150 to 2400 m asl. This association was the tree dominating association composed of moist temperate vegetation, including *Cedrus deodara* Roxb. ex D.Don, G.Don, *Viburnum grandiflorum* Wall. ex DC., *Achillea millefolium*

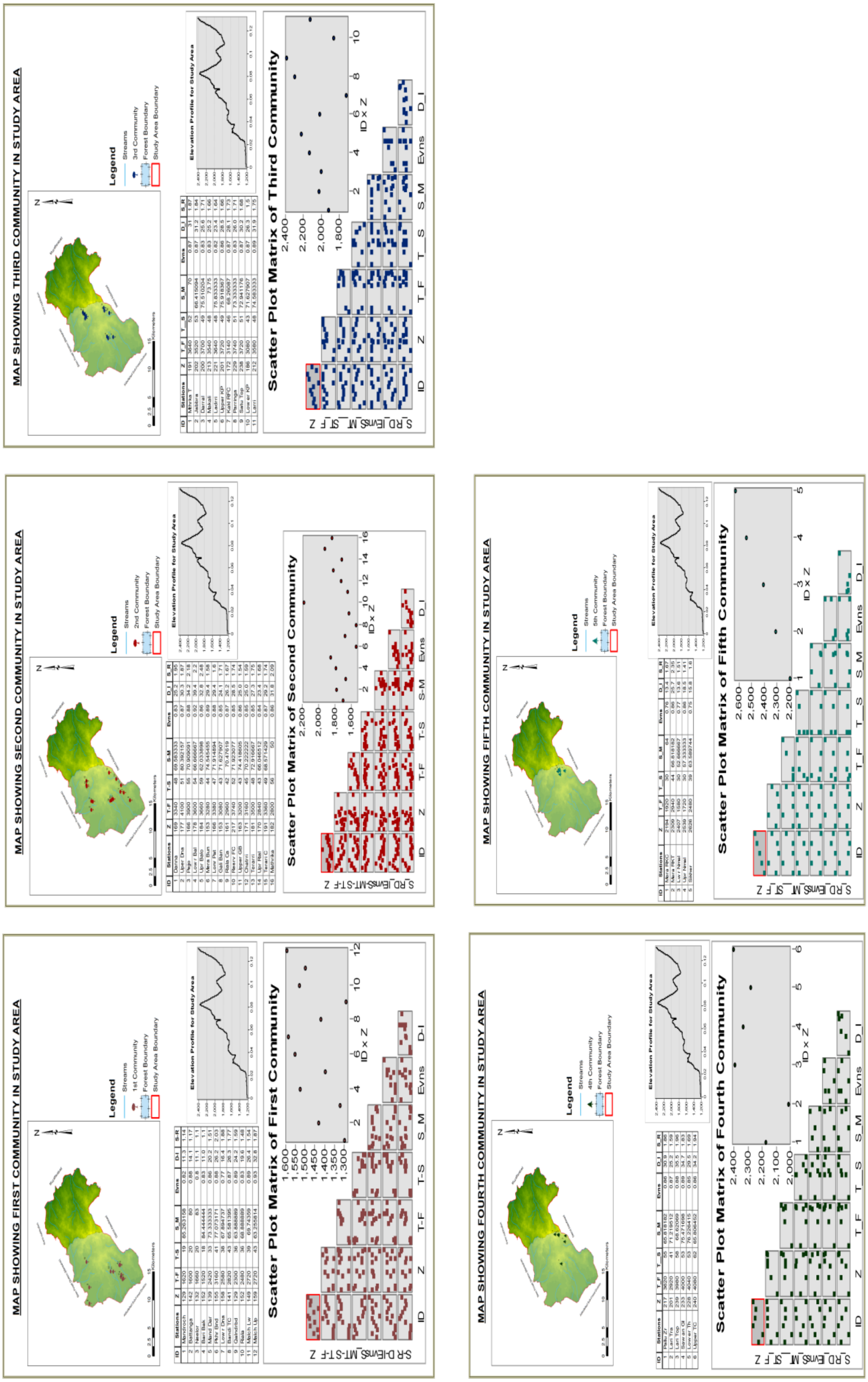

Figure 4. GIS generated map showing elevation profile in the scatter plot matrix of all the 5 plant associations/communities based on comparisons of the phytosociological attributes, i.e. D.I, Z, T.F, T.S, S.M & Ev.

Key: D.I = Diversity Index; Z = Elevation; T.F = Total Frequency; T.S = Total Species; S.M = Species Maturity; Ev = Evenness

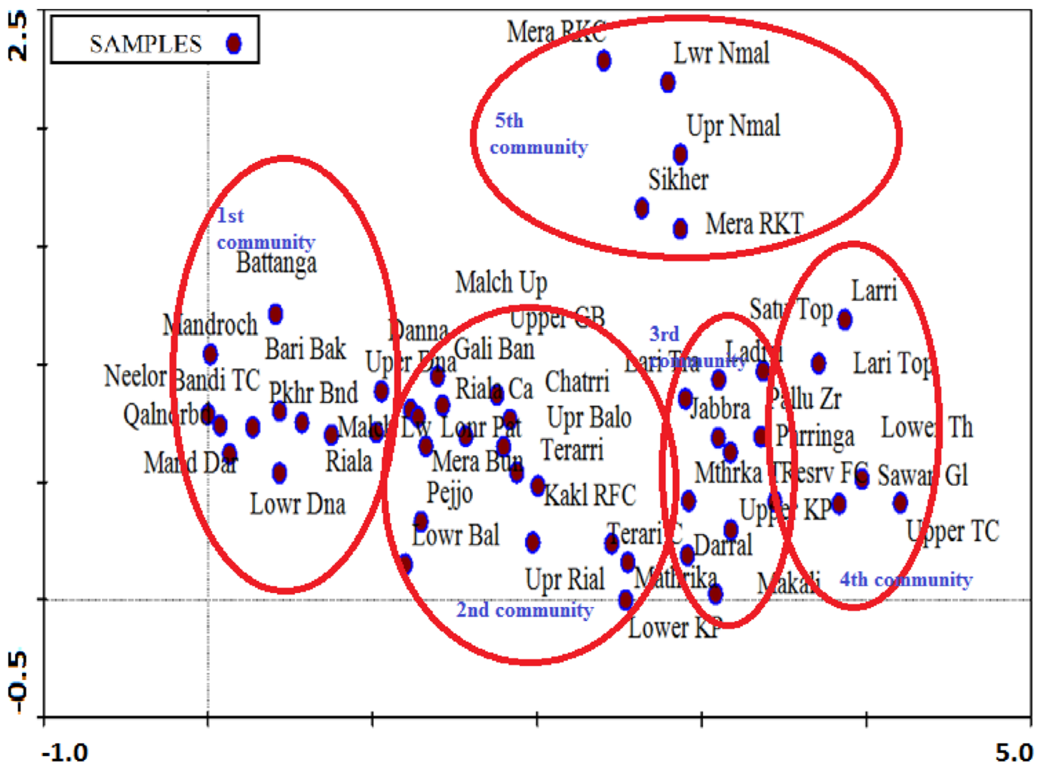

Figure 5. DCA plot showing the distribution of 50 stations/sampling sites among five plant associations/habitat types.

L., and *Abies pindrow* Royle. The important environmental variables determining this association were soil pH (ranging from 6 to 8) and sandy loam soil. This association develops in the middle higher regions of higher barometric pressure. Other environmental co-variables were electric conductivity, aspect, organic matter, and phosphorus contents in the soil. The main anthropogenic pressures on this association were the collection of medicinal plants and fodder and grazing of livestock (Figures 4–7).

3.2.5. Plant association of highest elevation (2400–2626 m)

This was the association of highest elevations in the TsFD, ranging from 2400 to 2626 m asl. The *Abies pindrow* Royle, *Daphne mucronata* Royle, and *Potentilla nepalensis* Hook. were the characteristic species of this association. High altitude and low temperature were the determinant factors prevailing throughout the growing season. This high elevational plant association has low species richness in contrast with other plant associations of the area. The pH of soil (slight acidic) was the important decisive environmental variable favouring growth and development of specific sorts of plant species in this association. Other co-variables were slightly higher phosphorous contents in the soil, low soil organic matter, and sandy loam soil (Figures 4–7).

3.3. Ecological gradient of plant associations

Correspondence analyses through CANOCO offer ecologists the choices to explore ecological gradients of vegetation directly through canonical correspondence analysis (CCA) or indirectly through detrended correspondence analysis (DCA). Results obtained through both sorts of technique are presented below.

3.3.1. Gradient analysis through DCA

A plant species matrix was used for DCA procedures, showing a long gradient length of the 1st axis that was equal to 4.205 SD (standard deviation) (Table 1). The primary two axes of DCA described 16.29% of the variance in the species data. The scatter plot of the data was generated as an ordination graph for better visual elucidation. The DCA diagrams indicate a continuous gradient in composition and diversity of species as well as association. The 1st axis demarcates the associations and habitats of the lower elevation from the higher one. Associations 1 and 2 occupy the left-hand side and associations 3 and 4 can be located on the right-hand side, while association 5 is located at the top side of the DCA diagram. In ecological terms, subtropical plant species are present at the lower elevation in association 1. Plant species of slightly dry habitats of forests (at lower–middle elevations and north-west aspect) and of more likely moist temperate habitats (at lower–

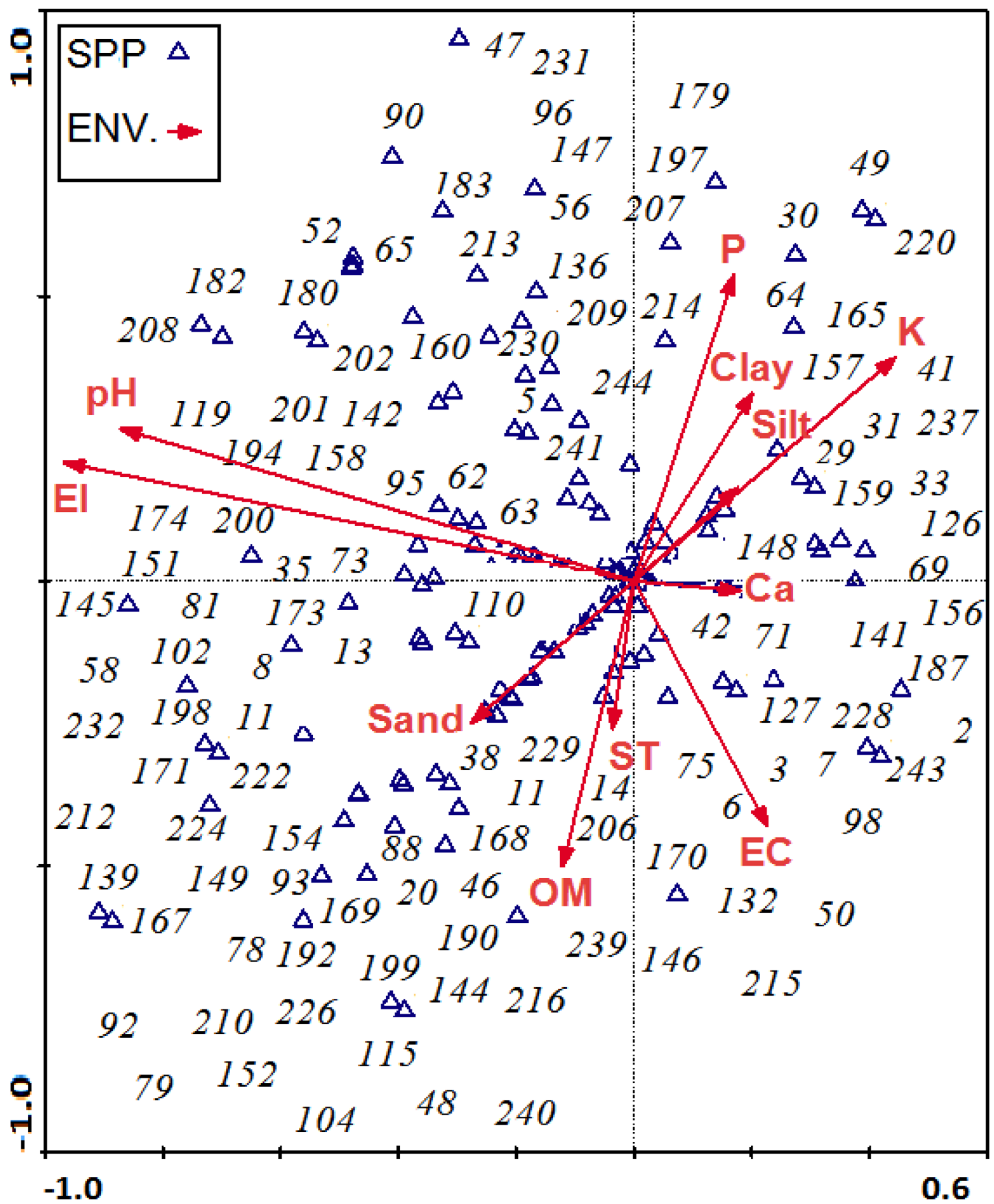

Figure 6. Canonical correspondence analysis (CCA) bi-plot showing distribution of 252 plant species in relation to 11 environmental variables.
P = Phosphorus, K = Potassium, Ca = Calcium, EC = Electrical Conductivity, OM = Organic Matter, ST = Soil Texture, El = Elevation, ENV = Environmental factors, SPP = Species.
(Plant species numbers and names are given in the Supplementary Table).

middle elevations with south-east aspect) are clustered in the middle of the graph (associations 2 and 3), while species of moist temperate habitats of a mesic nature (occurring at high elevations) are assembled in associations 4 and 5. Species richness and diversity increase from left to right up to the middle and then decrease up to the end at the right-hand side. The 2nd axis of the DCA plot showed the aspect variation of vegetation, i.e. by grouping the associations of north-west aspect slopes to the upper and south-east aspect to the lower side of the graph. As a whole the 2nd axis exhibits a geomorphological and physiographic gradient complex of relatively thin soils on south-eastern slopes to the shady surfaces of relatively deep soils of north-eastern slopes (Figure 5).

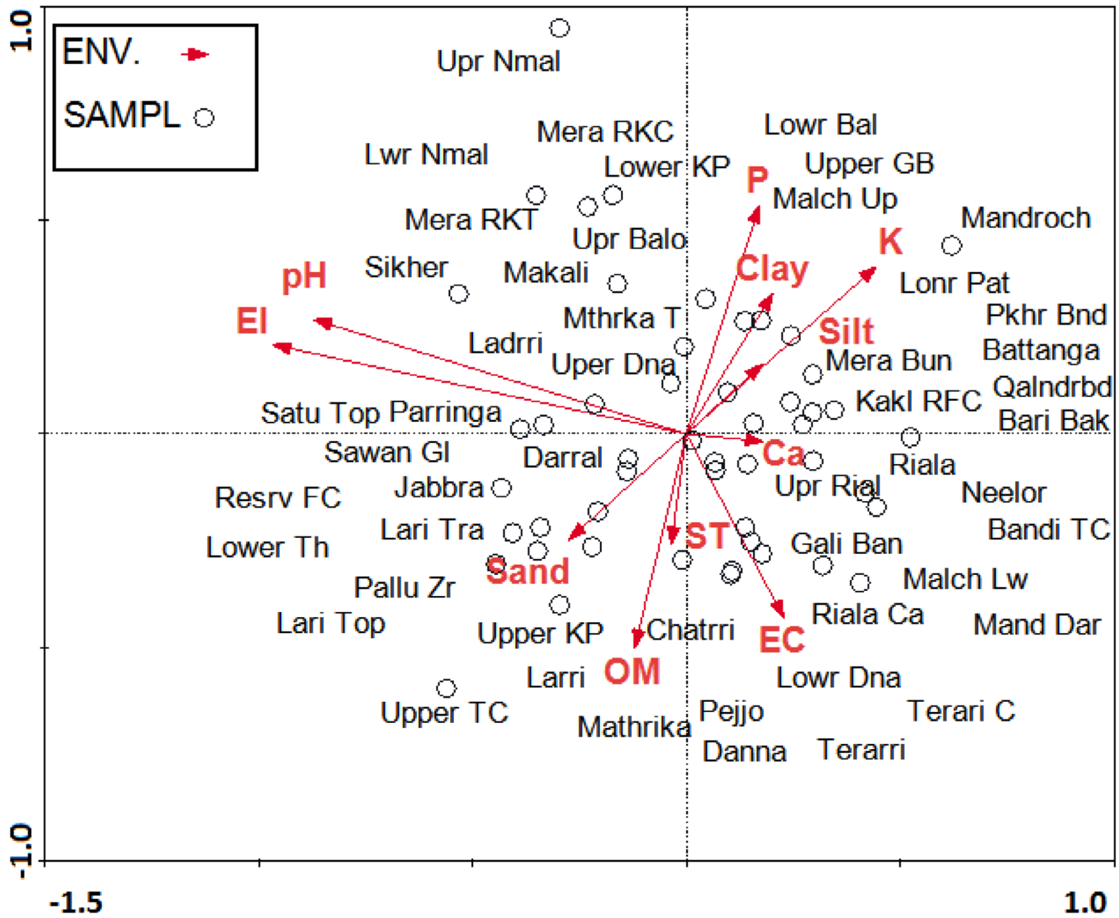

Figure 7. CCA bi-plot showing the distribution of 50 sampling sites/stations among five plant associations in relation to various environmental/ecological factors.
P = Phosphorus, K = Potassium, Ca = Calcium, EC = Electrical Conductivity, OM = Organic Matter, ST = Soil Texture, El = Elevation. SAMPL = Sampling sites/stations, ENV = Environmental factors.

Table 1. Summary the first four axes of DCA plot using detrended correspondence analyses, a multivariate ordination technique.

All the species (252) and all the stations/samples (50) were included					
Central lines	1	2	3	4	Total inertia
Eigen values	0.606	0.189	0.143	0.118	4.745
Extension of gradient	4.205	2.285	2.129	2.018	
Cumulative percentage (CP) variance of species data	12.8	16.8	19.8	22.2	

3.3.2. Gradient analysis through CCA

It was hypothesised that various environmental factors, i.e., aspect/slope, elevation, and soil composition, would be the key determinant factors for vegetation's variation and association formation in the region. To test this hypothesis, both the species and environmental data matrices were treated by CCA method together in CANOCO to examine whether the formation of plant associations was aligned with the measured environmental variables or not. Our findings showed high significance of these variables in the formation of plant associations in terms of test statistics ($P \leq 0.002$). The input of environmental data through CCA identified the ecological gradients for the constitution of a specific association type. The CCA graph (bi-plot) exhibited that both the composition and abundance of plant species were a reflection of the variations in

Table 2. Summary of the first four axes of the CCA for the vegetation data (using abundance/importance value data).

252 plant species, 50 stations/samples, and environmental variables were included in the analysis					
Axes	2	2	3	4	Total inertia
Eigen values	0.543	0.176	0.128	0.110	4.745
Species–environment associations	0.957	0.866	0.856	0.927	
Cumulative percentage variance of species data.	11.4	15.2	17.9	20.2	
Species–environment relation	37.2	49.3	58.1	65.6	
Summary of Monte Carlo test (499 permutations under reduced model).					
Test of significance of first canonical central lines (axes)		Test of significance of all canonical central lines (axes)			
Eigen value	0.543	Trace	1.458		
F-ratio	4.909	F-ratio	1.532		
P-value	0.0020	P-value	0.0020		

the ecological gradients like elevation, aspect, and soil composition, i.e. association 1 was distinguishable under the cumulative effect of electrical conductivity and least organic matter of the soil, associations 2 and 3 were unique under the influence of aspect, and associations 4 and 5 were prominent due to the impact of pH (P value ≤ 0.002). The determination of ecological gradient procedures through CCA both for stations and species advocates that the first axes was primarily associated with soil electrical conductivity and soil organic matter; the second axes were correlated mainly with aspect and partially with soil pH, texture, and phosphorous contents.

The strongest ecological variable of the 1st axes can be clearly conceded from the stations and species CCA diagrams (Figures 6 and 7). The stations + environmental bi-plots and species + environmental bi-plots confirm each other by making habitat and species association with the environmental data respectively. Pearson's correlations with ordination axes for the CCA plot pointed out a significant correlation of the axis with the geoclimatic variables (i.e. aspect, elevation, and soil composition). Pearson's correlations with CCA ordination axis indicate that the first axis (e = 0.543) was principally correlated with the soil EC (r = –0.2136). The second axis (e = 0.176) was correlated mainly with soil pH (r = 0.8867), while the third axis (e = 0.128) was associated partially with aspect (r = –0.514). The overall stations and species ordination diagrams utilised the first two axes (Table 2; Figures 6 and 7).

4. Discussion

Forest ecosystems all over the world usually have diverse biological associations due to their quickly changing microclimate, landscape, and geomorphological histories (Martijn and Herben, 2003; Fosaa, 2004; Khan et al., 2011). The distribution of individuals of the same and different plant species in a particular association is the application of microenvironmental impacts, time, and biotic relationships. The plant species congregate in an association in a definite fashion and hence can assist in vegetation quantification and evaluation. The classification of natural ecosystems into potential plant communities or associations and habitat types is important for the long-term management of natural resources (Ewald, 2003; Abbasi et al., 2013; Khan et al., 2016c; Rahman et al., 2016b). The vegetation classification and ordination also overcome problems of comprehension to some extent by summarising field data in a low-dimensional space with similar samples and species near together and dissimilar ones far apart (Smith, 2010; Khan et al., 2013c).

4.1. Phytogeographic distribution

Uneven topography, rough terrain, and far flung location make it difficult to sample vegetation intensively in the Western Himalayan region. Previous studies of plant associations in the developing world have often adapted conventional ways of phytosociological classifications, where the association names were given on the basis of dominant species having high importance values. In this paper we have adopted statistical and objective approaches for classification and ordination of plant associations. The DCA and CCA elucidated aspect, altitude, and soil chemical composition as the strongest explanatory variables. The results further revealed subtropical characteristic species in associations 1 and 2 at the lower elevations, for example *Pinus roxburghii* Sarg., *Punica florida* Salisb., *Dodonaea viscosa* (L.) Jacq., *Zanthoxylum armatum* DC., and *Zizyphus jujuba* Mill. On the other hand, the moist temperate zone can be classified into 3rd, 4th, and 5th associations with characteristics species of *Pinus wallichiana* A.B.Jacks., *Aesculus indica* (Wall. ex Cambess.) Hook, *Prunus padus* L., *Indigofera heterantha* Brandis, *Viburnum grandiflorum* Wall. ex DC., *Viburnum cotinifolium* D.Don., *Paeonia emodi* Royle, *Persicaria amplexicaulis* (D. Don) Ronse Decr., *Trifolium repens* L. etc. Similar sorts of plant assemblages have also been observed in adjacent moist temperate locations by a number of researchers and can be seen in the literature (Wazir et al., 2008; Saima et al., 2009; Shaheen et al., 2011; Khan et al., 2015). Vegetation of the studied area appears between the subtropical and moist-temperate zones having Sino-Japanese and Irano-Turanian floristic elements. On the basis of the definition of ecotone provided by Peters et al. (2006), as a zone where a directional spatial change in vegetation is faster than on either side of the zone, we advocate that the TsFD occupies a sort of transitional floristic position between these two regions. Studies of the adjacent mountain ranges, the Karakorum and the Hindu Kush (Nüsser and Clemens, 1996; Chawla et al., 2008; Chevallier et al., 2011), also confirmed many of the Himalayan regions as a transitional location on the edge of the moist and dry temperate zones of the Western Himalayan Province on one side and subtropical on the other. Our findings showed strong moist temperate floral elements within the vegetation, with the overall dominance of herbaceous species (61%), which can be seen in the publication based on studies on the Indian parts of the Himalayas (Kharkwal et al., 2005). Zobel and Singh (1997) wrote that such vegetation features can be expected in the Himalayas, and western parts of the Himalayas (like our study area) are becoming more like the Hindu Kush and the Karakorum mountain ranges rather than the eastern Himalayas itself. Similar to our 1st and 2nd associations, Siddiqui et al. (2009) reported phytosociological communities of *Pinus roxburghii* Sarg. (Chir pine) in the Lesser Himalayan and Hindu Kush range of Pakistan. Saima et al. (2009), also reported *Pinus wallichiana* A.B.Jacks. communities but with different dominant species from the Ayubia National Park, Abbottabad. Effects of soil pH, slope, and aspect in species zonations were also observed by a number of authors in other mountain systems around the globe like ours and can be seen in the published literature (Hegazy et al., 1998; Wang and Singh, 2006; Davies et al., 2008; Khan et al., 2012). The above-mentioned studies differ from ours as they lack the use of any sort of statistical analyses.

4.2. Use of database technology in vegetation monitoring

Management and monitoring of plant habitats and restoration of the disturbed one requires multiscale techniques. The GEO database is a suitable database for managing ecological data for monitoring purposes. It eases the data processing for meta-analysis via producing manageable structures and standardisation from dispersed data sources (Safford et al., 2005). Such a database combines ArcMap data with Microsoft Access for single entry, processing, storage, organisation, visualisation, and analyses. This sort of data set then not only allows use of topology and rules application for data quality control and covers re-classification, but also serves as a beneficial organisational receptacle within a GEO database. The execution of this GIS framework also aids spatial modelling, which ultimately helps in the recognition of indicator species of a specific habitat or association.

4.3. Conservation management

This study has several important suggestions for the modelling and planning of guzara and reserve forests areas. The study reveals that TsFD areas within upland forests are certainly a valuable resource for the conservation of plant biodiversity as these host high species richness and a number of infrequent species. The plant associations in these habitats represent distinctive amalgamations of different plant species. Clearly, moist temperate and subtropical habitats in Thandiani forests establish an ideal ground for conservation. Ecologists and conservation practitioners often neglect small forested regions in part due to a lack of clear denotation of habitat types. By identifying indicators for a representative zone (Khan et al., 2016b) and the finding presented here should facilitate the recognition and conservation of these valuable plant association types. Forest and habitat types identified here will also help all the stakeholders to understand the relative conservation value of different sites and plant biodiversity.

It is concluded from this study that the ecological gradient of the region has vital role in the determination of various plant associations of the area. Individual plant species and associations changed with the change in topographic, edaphic, and climatic gradients both qualitatively and quantitatively. Plant ecologists have commonly been conscious that vegetation shows a discrepancy over a broad variety of specific variables in an ecosystem. Therefore, it was necessary to apply such multifold approaches and methods through CANOCO and GEO database to document the present-day status and make a way for future conservation management of plant biodiversity in the studied as well as adjacent regions.

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Supplementary Table. Plants names and their number as used in the CCA biplot.

S. no.	Botanical name
1	*Abies pindrow* (Royle ex D.Don) Royle
2	*Acacia arabica* (Lam.) Muhl. ex Willd.
3	*Acacia nilotica* (L.) Delile
4	*Acer caesium* (Reinw. ex Blume) Kosterm.
5	*Aesculus indica* (Wall. ex Cambess.) Hook.
6	*Ailanthus altissima* (Mill.) Swingle
7	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.
8	*Cedrela serrata* Royle
9	*Cedrela toona* var. *australis* (F.Muell.) C.DC.
10	*Cedrus deodara* (Roxb. ex D.Don) G.Don
11	*Celtis australis* (Willd.) C.C.Towns.
12	*Cornus macrophylla* Wall.
13	*Cotoneaster minuta* Saporta
14	*Dalbergia sissoo* DC.
15	*Diospyros kaki* L.f.
16	*Diospyros lotus* L.
17	*Eucalyptus globulus* Labill.
18	*Ficus carica* L.
19	*Ficus palmata* Forssk.
20	*Grewiaoptiva* J.R.Drumm. ex Burret
21	*Ilex dipyrena* Wall.
22	*Jacaranda mimosifolia* D.Don
23	*Juglans regia* L.
24	*Melia azedarach* L.
25	*Morus alba* L.
26	*Morus nigra* L.
27	*Olea ferruginea* Wall. ex Aitch.
28	*Pinus roxburghii* Sarg.
29	*Pinus wallichiana* A.B.Jacks.
30	*Pistacia integerrima* J.L.Stewart ex Brandis
31	*Platanus orientalis* L.
32	*Populus ciliata* Wall. ex Royle
33	*Populus nigra* L.
34	*Prunus armeniaca* L.
35	*Prunus domestica* L.
36	*Prunus padus* L.
37	*Prunus persica* (L.) Batsch
38	*Pyrus pashia* Buch.-Ham. ex D.Don
39	*Quercus dilatata* Royle
40	*Quercus incana* Bartram
41	*Robiniapseudo acacia* L.
42	*Salix alba* L.

S. no.	Botanical name
43	*Salix angustifolia* Willd.
44	*Salix denticulate* Andersson
45	*Sarcococca saligna* Müll.Arg.
46	*Sorbariato mentosa* (Lindl.) Rehder
47	*Staphylea emodi* Wall. ex Brandis
48	*Taxus wallichiana* Zucc.
49	*Ulmus wallichiana* Planch.
50	*Vincetoxicum arnottianum* (Wight) Wight
51	*Ziziphus vulgaris* Lam.
52	*Abelia triflora* R.Br. ex Wall.
53	*Andrachne cordifolia* (Decne.) Müll.Arg.
54	*Arundo donax* L.
55	*Astragalus aaronii* (Eig) Zohary
56	*Berberis lyceum* Royle
57	*Berberis orthobotrys* Bien. ex Aitch.
58	*Berberis pachyacantha* Bien. ex Koehne
59	*Berberis parkeriana* C.K.Schneid.
60	*Buddleja asiatica* Lour.
61	*Buddleja crispa* Benth.
62	*Buxus papillosa* C.K.Schneid.
63	*Clematis amplexicaulis* Edgew.
64	*Clematis montana* Buch.-Ham. ex DC.
65	*Cuscuta reflexa* Roxb.
66	*Daphne mucronata* Royle
67	*Debregea siasaeneb* (Forssk.) Hepper & J.R.I.Wood
68	*Desmodium gangeticum* (L.) DC.
69	*Desmodium podocarpum* Hook. & Arn.
70	*Dodonaea viscosa* (L.) Jacq.
71	*Euonymus hamiltonianus* Wall.
72	*Hedera nepalensis* K.Koch
73	*Indigofera gerardiana* Baker
74	*Indigofera heterantha* Brandis
75	*Isodon coetsa* (Buch.-Ham. ex D.Don) Kudô
76	*Lonicera hispida* Pall. ex Schult.
77	*Lonicera bicolor* Klotzsch
78	*Lonicera quinquelocularis* Hard.
79	*Parrotiopsis jacquemontiana* (Decne.) Rehder
80	*Paeonia emodi* Royle
81	*Punica granatum* L.
82	*Rhamnus purpurea* Edgew.
83	*Rhus punjabensis* J.L.Stewart ex Brandis
84	*Rosa abietina* Gren. ex H.Christ

S. no.	Botanical name
85	*Rosa webbiana Wall.* ex Royle
86	*Rubus ellipticus* Sm.
87	*Rubus fruticosus* L. sens. str.
88	*Rubus macilentus* Jacquem. ex Cambess.
89	*Rubus ulmifolius* Schott
90	*Sagereti abrandrethiana* Aitch.
91	*Skimmia laureola* Franch.
92	*Solanum pseudocapsicum* L.
93	*Spiraea gracilis* Maxim.
94	*Syringa emodi* Wall. ex Royle
95	*Viburnum cotinifolium* D.Don
96	*Viburnum grandiflorum* Wall. ex DC
97	*Vitex negundo* L.
98	*Zanthoxylum armatum* DC.
99	*Ziziphus jujuba* Mill.
100	*Achillea millefolium* L.
101	*Achyranthus* spp.
102	*Aconitum violaceum* Jacquem. ex Stapf
103	*Actaea spicata* L.
104	*Adiantum venustum* D.Don
105	*Aegopodium* burttii Nasir
106	*Ainsliaea aptera* DC.
107	*Ajuga integrifolia* Buch.-Ham.
108	*Anemone falconeri* Thomson
109	*Anemone tetrasepala* Royle
110	*Anemone vitifolia* Buch.-Ham. ex DC.
111	*Aquilegia mussooriensis* Royle
112	*Aquilegia pubiflora* Wall. ex Royle
113	*Argemone mexicana* L.
114	*Arisaema flavum* (Forssk.) Schott
115	*Arisaema jacquemontii* Blume
116	*Arisaema utile* Hook.f. ex Schott
117	*Artemisia absinthium* L.
118	*Aster molliusculus* (Lindl. ex DC.) C.B.Clarke
119	*Atropa acuminata* Royle ex Lindl.
120	*Bergenia ciliata* (Haw.) Sternb.
121	*Bistorta amplexicaulis* (D.Don) Greene
122	*Bupleurum candollei* Wall. ex DC.
123	*Bupleurum falcatum* L.
124	*Bupleurum jucundum* Kurz
125	*Bupleurum lanceolatum* Wall. ex DC.
126	*Calamintha vulgaris* (L.) Druce
127	*Cannabis sativa* L.
128	*Capsella bursa-pastoris* (L.) Medik.
129	*Capsicum annuum* L.
130	*Caryopteris odorata* (D.Don) B.L.Rob.
131	*Chenopodium album* L.
132	*Chrysanthemum cinerariifolium* (Trevir.) Vis.
133	*Cichorium intybus* L.
134	*Cirsium argyracanthum* DC.
135	*Cnicus argyracanthus* (DC.) C.B.Clarke
136	*Colchicum luteum* Baker
137	*Convolvulus prostratus* Forssk.
138	*Conyza canadensis* (L.) Cronquist
139	*Coriandrum sativum* L.
140	*Corydalis diphylla* Wall.
141	*Corydalis cornuta* Royle
142	*Cynodon dactylon* (L.) Pers.
143	*Cyperus rotundus* L.
144	*Datura stramonium* L.
145	*Dicliptera chinensis* (L.) Juss.
146	*Dioscorea bulbifera* L.
147	*Dipsacus sativus* (L.) Honck.
148	*Dipsacus inermis* Wall.
149	*Dryopteris* spp.
150	*Duchesnea indica* (Jacks.) Focke
151	*Echinops niveus* Wall. ex Wall.
152	*Elaeagnus parvifolia* Wall. ex Royle
153	*Ephedra gerardiana* Wall. ex Stapf
154	*Epilobium royleanum* Hausskn.
155	*Epipactis helleborine* (L.) Crantz
156	*Erigeron roylei* DC.
157	*Eulophia hormusjii* Duthie
158	*Euphorbia helioscopia* L.
159	*Euphorbia hirta* L.
160	*Euphorbia wallichii* Hook.f.
161	*Foeniculum vulgare* Mill.
162	*Fragaria nubicola* (Lindl. ex Hook.f.) Lacaita
163	*Galium aparine* L.
164	*Galium asperifolium* Wall.
165	*Galium elegans* Wall. ex Roxb.
166	*Galium hirtiflorum* Req. ex DC.
167	*Geranium wallichianum* D.Don ex Sweet
168	*Girardinia palmata* (Forssk.) Gaudich.
169	*Gnaphalium affine* D.Don
170	*Heliotropium paniculatum* R. Br.

S. no.	Botanical name
171	*Heracleum candicans* Wall. ex DC.
172	*Hyoscymus niger* L.
173	*Hypericum oblongifolium* Choisy
174	*Hypericum perforatum* L.
175	*Impatiens balsamina* L.
176	*Impatiens bicolor* Royle
177	*Impatiens edgeworthii* Hook. .
178	*Impatiens flemingii* Hook.f.
179	*Jasminum officinale* L.
180	*Gerbera gossypina* (Royle) Beauverd
181	*Lactuca brunoniana* (DC.) Wall. ex C.B.Clarke
182	*Lavatera cashemiriana* Cambess.
183	*Lecanthus peduncularis* (Wall. ex Royle) Wedd.
184	*Lepidium sativum* L.
185	*Lyonia ovalifolia* (Wall.) Drude
186	*Malcolmia africana* (L.) R.Br.
187	*Malva neglecta* Wallr.
188	*Malva sylvestris* L.
189	*Medicago denticulata* Willd.
190	*Mentha longifolia* (L.) L.
191	*Micromeria biflora* (Buch.-Ham. ex D.Don) Benth.
192	*Myosotis asiatica* (Vestergr.) Schischk. & Serg.
193	*Myrsine africana* L.
194	*Nepeta erecta* (Royle ex Benth.) Benth.
195	*Nerium oleander* L.
196	*Oenothera rosea* L'Hér. ex Aiton
197	*Onychium contiguum* C.Hope
198	*Orchid* spp.
199	*Otostegia limbata* (Benth.) Boiss.
200	*Oxalis corniculata* L.
201	*Papaver somniferum* L.
202	*Phalaris minor* Retz.
203	*Phytolacca latbenia* (Moq.) H.Walter
204	*Pimpinella acuminata* (Edgew.) C.B.Clarke
205	*Plectranthus rugosus* Wall. ex Benth.
206	*Plantago lanceolata* L.
207	*Plantago major* L.
208	*Poa annua* L.
209	*Podophyllum emodi* Wall. ex Hook.f. & Thomson
210	*Podophyllum hexandrum* Royle
211	*Polygonatum verticillatum* (L.) All.

S. no.	Botanical name
212	*Polygonum amplexicaule* D.Don
213	*Potentilla fruticosa* L.
214	*Potentilla nepalensis* Hook.
215	*Primula veris* L.
216	*Prunella vulgaris* L.
217	*Pseudomertensia parviflorum* (Decne.) Riedl
218	*Pteris vittata* L.
219	*Ranunculus laetus* Wall. ex Hook. f. & J.W.Thomson
220	*Ranunculus muricatus* L.
221	*Reinwardtia indica* Dumort.
222	*Rochelia stylaris* Boiss.
223	*Rumex dentatus* L.
224	*Rumex hastatus* D.Don
225	*Rumex nepalensis* Spreng.
226	*Salvia moorcroftiana* Wall. ex Benth.
227	*Sauromatum venosum* (Dryand. ex Aiton) Kunth
228	*Scrophularia robusta* Pennell
229	*Scutellaria linearis* Benth.
230	*Senecio chrysanthemoides* DC.
231	*Sibbaldia cuneata* Schouw ex Kunze
232	*Silene vulgaris* (Moench) Garcke
233	*Silybum marianum* (L.) Gaertn.
234	*Solanum americanum* Mill.
235	*Sonchus arvensis* L.
236	*Strobilanthes wallichii* Nees
237	*Swertia alata* C.B.Clarke
238	*Swertia angustifolia* Buch.-Ham. ex D.Don
239	*Swertia ciliata* (D.Don ex G.Don) B.L.Burtt
240	*Tagetes minuta* L.
241	*Taraxacum officinale* (L.) Weber ex F.H.Wigg.
242	*Thalictrum cultratum* Wall.
243	*Themeda anathera* (Nees ex Steud.) Hack.
244	*Trifolium repens* L.
245	*Tussilago farfara* L.
246	*Urtica ardens* Link
247	*Valeriana jatamansi* Jones
248	*Valeriana officinalis* L.
249	*Verbascum thapsus* L.
250	*Verbena bonariensis* L.
251	*Viola biflora* L.
252	*Viola canescens* Wall.