# ENVIRONMENTAL DETERMINANTS OF VEGETATION IN DISTRICT MALAKAND, A SUB-TROPICAL ZONE OF THE OUTER HINDU KUSH MOUNTAIN RANGE

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**Abstract.** This study evaluates plant species composition, distribution pattern, formation of different plant associations and their respective indicators in relation to various environmental factors in the district Malakand, Hindu Kush Mountain. Quadrat quantitative ecological techniques were used for sampling vegetation. All the collected plant species and environmental data were analyzed using PC-ORD and CANOCO software. The present study explored 382 plant species belonging to 91 different families. Based on the number of species, Poaceae (sp., 48), therophytes (169 sp., 44.2%), and microphylls (185 sp., 48.4%) were the dominant family, life form and leaf form class, respectively. Cluster analysis and Two-way cluster analysis identified five plant associations i.e. (1) *Acacia-Ziziphus-Asphodelous* association (2) *Morus-Saccharum-Phalaris* association (3) *Salix-Debregeasia-Agrostis* association (4) *Monotheca-Rhazya-Aerva* association and (5) *Phoenix-Myrsine-Viola* association. CCA results showed that topographic and edaphic variables (altitude, aspect, landscape, soil texture, electrical conductivity, pH, total soluble solutes, calcium carbonates, organic matter, nitrogen, phosphorous and potassium) significantly influenced species distribution and vegetation structure. The present study can be utilized in ecology as a baseline for further research for analyzing vegetation structure and identifying its associated indicators.
**Keywords:** *vegetation structure, edaphic factors, plant association, multivariate analysis, Malakand, Hindu Kush range*

## Introduction

Vegetation is the expression of several environmental factors in a specific time at a particular location (Khan et al., 2012; Manan et al., 2020). It is the outcome of the interaction of many factors, including biotic and non-biotic intervention (Rawat et al., 2020; Karami et al., 2021). Ecological studies are conducted to correlate abiotic and biotic components of the ecosystem (Rahman et al., 2016, Ye et al., 2020). Hence, the researcher checks and studies the distribution of species under the impact of environmental variables. Environmental factors play a dynamic role in plant growth (Wang et al., 2016). For example, physicochemical features of the soil influence species richness, abundance, and diversity. Site gradients influence the floristic composition, density, distribution, and diversity of the vegetation (Bernard-Verdier et al., 2012; Boulangeat et al., 2012; Zhuang et al., 2012). Similarly, vegetation is influenced by several natural and anthropogenic disturbances on local and broader scales (Ali et al., 2002; Bai et al., 2004; Dhyani et al., 2019; Tiwari et al., 2020).

Classifying vegetation into units (associations) was pioneered by Braun-Blanquet based on characteristics of species and floristic composition (Enright and Nuñez, 2013; Liu et al., 2020). The composition and structure of vegetation can be described based on several qualitative and quantitative features (Khare et al., 2019; Hauchhum et al., 2020;


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Paing et al., 2021). The quantitative analysis evaluates vegetation structure precisely (Singh et al., 2014). The quantitative vegetation analysis is a crucial criterion to plan and interpret long-term ecological research (Phillips et al., 2003). The multivariate techniques have been applied to expose the fundamental environmental factors responsible for shaping vegetation structure to remarkable effectiveness (Khan et al., 2013). Cluster and two-way cluster analysis classify the vegetation into different communities (Siddiqui et al., 2010). Canonical correspondence analysis (CCA) provides a better interpretation of ecological data underlying vegetation. Similarly, detrended correspondence analysis (DCA) provides more robust and interpretable results (Cazier and Ware, 2001).

In ecological studies, it is very crucial to investigate the environmental effect on the vegetation pattern using different statistic techniques (Ahmad et al., 2016; Adil et al., 2017; Iqbal et al., 2017; Khan et al., 2017b, 2018; Abdel Khalik et al., 2017). However, few studies have been available in the literature in terms of Hindu Kush mountain.

It is widely accepted since Humboldt's work on phytogeography in the 1800s that plant associations are affected by edaphic and climatic factors. District Malakand is a biological corridor in the great Hindu Kush mountain range. This sub-tropical zone is considered to be the hub to vegetation due to its favorable climatic parameters. The available literature on vegetation dynamics in relation to edaphic and topographic factors showed that this region is unexplored. Therefore, our research study aims to analyze the impact of various environmental factors on the vegetation dynamics using robust multivariate statistical techniques in the subtropical mountainous zone of the Hindu Kush range, District Malakand, Pakistan. The techniques used in the current investigation can be used as a baseline for further studies in ecology for the classification of different plant communities/associations and their respective indicator species.

## Materials and Methods

### *Study area*

District Malakand is located in the northern side of Khyber Pakhtunkhwa (KP) province, in the outer range of Hindu Kush Mountains of Pakistan. Because of its varied climate, the area possesses luxuriant vegetation and possesses elements of Sino-Japanese phytogeographical region (Rahman, 2012). Malakand has a total area of 952 sq. km with a population size of 720,295. It shares its boundaries with Swat, Dir, Buner, Charsadda, Mardan, Bajaur and Mohmand (*Figs. 1, 2*). Geographically, Malakand holds great importance as it connects Chitral, Bajaur, Dir and Swat with the province's main cities such as Peshawar, Mardan, Charsadda and Nowshera.

The landscape is represented by both plain as well as hilly regions. In the hilly terrain, Hazar Nao hill is the highest peak having an altitude of 2727 meters. The hills have many metallic, non-metallic and industrial minerals such as slate stone, marble, granite and chromite. The plain area is fertile and many types of crops are grown by farmers in the cultivated lands. River Swat irrigates these cultivated lands. The agriculture, horticulture and mining sectors present various opportunities to uplift the economy of the people. A significant portion of households depends on livestock for their livelihoods (Shah, 2019). Wheat, maize, rice and sugarcane are the main crops of this region. The district can become a major horticulture supplier of fruits as it is the third-highest producer in the province. The area is also suitable for olive tree cultivation to produce edible oil. The sampling stations in the present study had an altitude of 430 - 1072 meters that lie at a latitude of 34° 41' 92" to 34° 63' 65" North and longitude of 71° 66' 67" to 72° 19' 87"


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East. The sampled stations vary from each other by having differences in several edaphic and topographic features (*Table 1*).

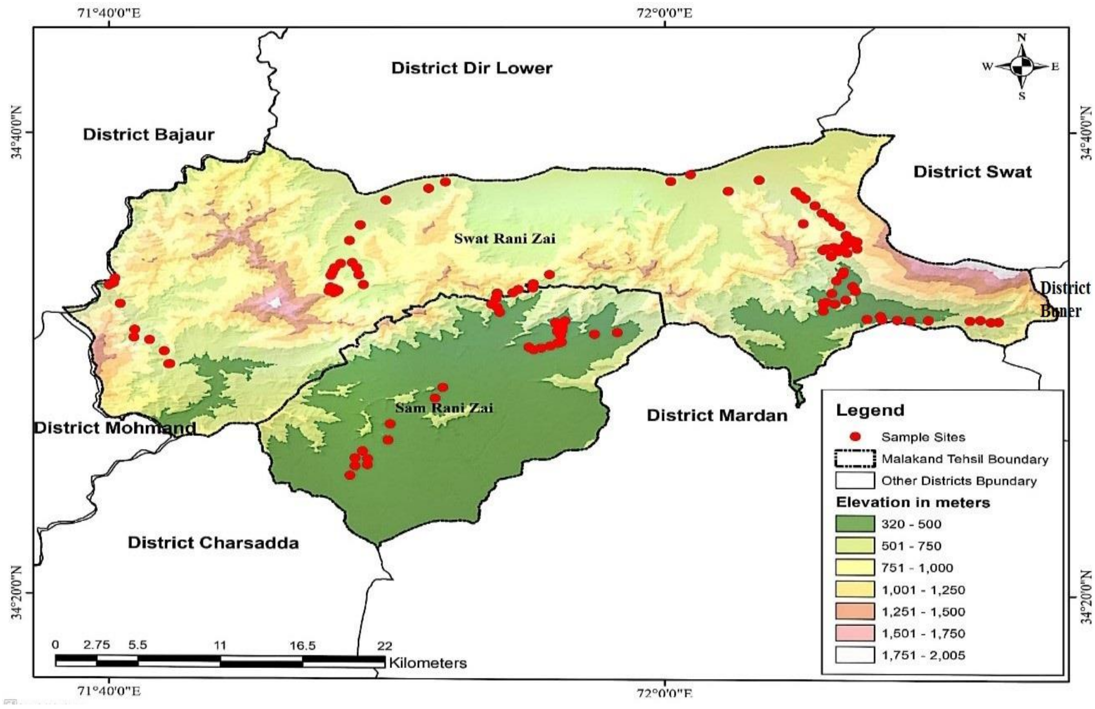


***Figure 1.*** *Map of the research study area, District Malakand.*


***Figure 2.*** *Pictorial view of the study area, (a) Lush green vegetation at station-7 (north aspect), (b) Thick vegetation at station-12 (south aspect), (c) View of vegetation at station-4 (north aspect) (d), Another look of vegetation at lower reaches of station-7*


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***Table 1.*** *Landscape, altitude and geographic coordinates of the sampling sites*

| Station No. & name | Landscape/ Aspect | Altitude (m) | Altitude type | Geographic coordinates | |
|---|---|---|---|---|---|
| | | | | Latitude (N) | Longitude (E) |
| 1. Palai | Plain | 494-531 | Low | 34.538486-34.566793 | 72.094491-72.113713 |
| 2. Bazdara | Plain | 496-660 | Low | 34.530209-34.534506 | 72.120600-72.198706 |
| 3. Palai-Thana | Hill (south) | 625-1050 | High | 34.577700-34.586245 | 72.094303-72.114576 |
| 4. Palai-Thana | Hills (north) | 765-1072 | High | 34.546316-34.605901 | 72.098013-72.114616 |
| 5. Thana | Plain | 670-800 | Middle | 34.601248-34.636570 | 72.003585-72.093846 |
| 6. Totakan | Plain | 612-675 | Middle | 34.556878-34.631025 | 71.805873-71.868756 |
| 7. Baika-Chapal | Hill (north) | 690-1110 | High | 34.551081-34.568990 | 71.798991-71.804385 |
| 8. Malakand Pass | Hill (south) | 534-829 | Middle | 34.537067-34.564329 | 71.896334-71.931110 |
| 9. Wartair | Plain | 468-517 | Low | 34.510071-34.530854 | 71.918738-71.971611 |
| 10. Jaban-Dargai | Watercourse | 463-520 | Low | 34.515374-34.529673 | 71.935134-71.938693 |
| 11. Palonao | Plain | 430-454 | Low | 34.419211-34.482823 | 71.811648-71.867221 |
| 12. Dheri-Kandao | Hill (south) | 501-688 | Middle | 34.49932-34.561230 | 71.666670-71.703456 |

### *Vegetation sampling*

Several preliminary visits were conducted for sites selection during the years of 2019-20. As a complete result, the region was categorized into twelve sites. At each site, quadrats were taken randomly for the sampling of vegetation. Herbs, shrubs, and trees were quantitatively analyzed with 1 sq. meter, 5 sq. meter, and 10 sq. meter quadrats. Altitude and geographic coordinates were recorded for each stand using the Global Positioning System (GPS) (Yang et al., 2016). Various phytosociological approaches were applied for quantitative analyses of vegetation. Plant specimens were collected and preserved properly. According to the flora of Pakistan (Nasir and Ali, 1971-1989; Ali and Qaiser, 1991-2019) and other available literature, the plant specimens were identified. The biological spectrum was determined using the approach of Raunkiaer (1934).

### *Soil samples analyses*

About 1 kg soil samples were collected from each site up to 15 cm in depth (Ahmad et al., 2019; Anwar et al., 2019; Manan et al., 2020). Soil samples were packed in plastic bags and were appropriately tagged. These samples were physicochemically analyzed in the Soil Science Laboratory of the Agricultural Research Institute (ARI), Tarnab, Peshawar, Pakistan. Soil texture was determined using a hydrometer method following the standard method of Brady (1990). Soil pH was determined by testing a 1:5 soil: water suspension with a pH meter (Jackson, 1992). Electrical conductivity (EC) was determined with a conductivity meter AD-3000 (Slavich and Petterson, 1993). Soil moisture content (MC) was determined by the gravimetric method, as indicated by Gardner (1986). The $CaCO_3$ was determined by acid neutralization method (Allison, 1965; Kalra, 1971). Organic matter (OM) was determined using the Walky-Black procedure (Rhoades, 1982). Total soluble solutes (TSS) were determined using method of AOAC (1984). Nitrogen (N) was determined using the Kjeldhal method (Bremner and Mulvaney, 1982) while Phosphorus (P) and Potassium (K) were determined using the methods described by Olsen & Sommers (1982) and Rhoades (1982), respectively.

### *Data analyses*

After completing eco-floristic data, data matrices were prepared in Excel for further analyses using PC-ORD (ver. 5) and CANOCO (ver. 4.5) software. The cluster analysis was used for the interpretation of the distribution of plant species. The CANOCO was used to analyze various environmental data i.e., altitude, aspect, soil texture (clay, silt, sand), pH, EC, TSS, organic matter, $CaCO_3$, N, P and K on plant species distribution. The ordination results were presented in the form of ordination graphs/plots. The species-area curve (SAC) was constructed using the Sorenson measure to assess adequacy of the sampled size. Plant associations were named based on the top three indicator plant species, identified by indicator species analysis (ISA), as suggested by Dufrêne and Legendre (1997).

## Results

### *Floristic diversity*

A total of 382 plant species were identified belonged to 289 genera of 91 different families from the subtropical zone of Hindu Kush mountainous range. Based on habit of plants, there were 290 (76%) species of herb, 46 (12%) shrubs, 39 (10%) trees and 7 (2%) shrubby climbers. The top 10 leading families based on possessing number of species were Poaceae (sp., 48) accompanied by Asteraceae (sp., 34), Papilionaceae (sp., 24), Lamiaceae (sp., 17), Brassicaceae (sp., 15), Amaranthaceae (sp., 13), Boraginaceae (sp., 13), Euphorbiaceae (sp., 11), Scrophulariaceae (sp., 11) and Cyperaceae (sp., 10).

### *Biological spectrum*

The life form spectrum of the studied mountainous region showed that therophytes (169 sp., 44.2%) followed by hemicryptophytes (81 sp., 21.2%) and nanophanerophytes (39 sp., 10.2%) were the dominant leaf size classes. The other leaf size classes included chamaephytes (24 sp., 6.3%), mesophanerophytes (20 sp., 5.2%), microphanerophytes (13 sp., 3.4%), megaphanerophytes (18 sp., 4.7%) and geophytes (18 sp., 4.7%). The dominant leaf size spectrum was microphylls (185 sp., 48.4%) followed by nanophylls (107 sp., 28.0%) and mesophylls (61 sp., 16.0%). The other leaf size classes were leptophylls (21 sp., 5.5%) megaphylls (4 sp., 1.0%) and aphyllous (4 sp., 1.0%).

### *Classification of plant associations*

#### *Species area curve*

Species area curve (SAC) was used to confirm the adequate sample size for assessing vegetation in the studied area. SAC showed that the maximum number of new plant species appearing high up to station/quadrat number 80. After that the curves become parallel, which comprehends adequate sampling in the mountainous region (*Fig. 3*).

#### *Cluster Analysis (CA)*

The CA of PC-ORD v.5 classified all the stations/quadrats and plant species into 5 major plant associations (*Fig. 4*). The detail description of each association along with their respective indicators and environmental gradient are as follows.


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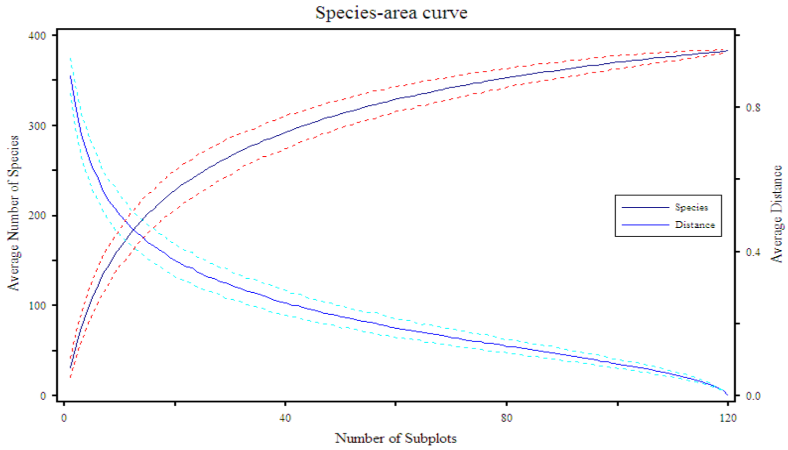


***Figure 3.*** *Species area curve for 382 plant species in relation to sampling stations*

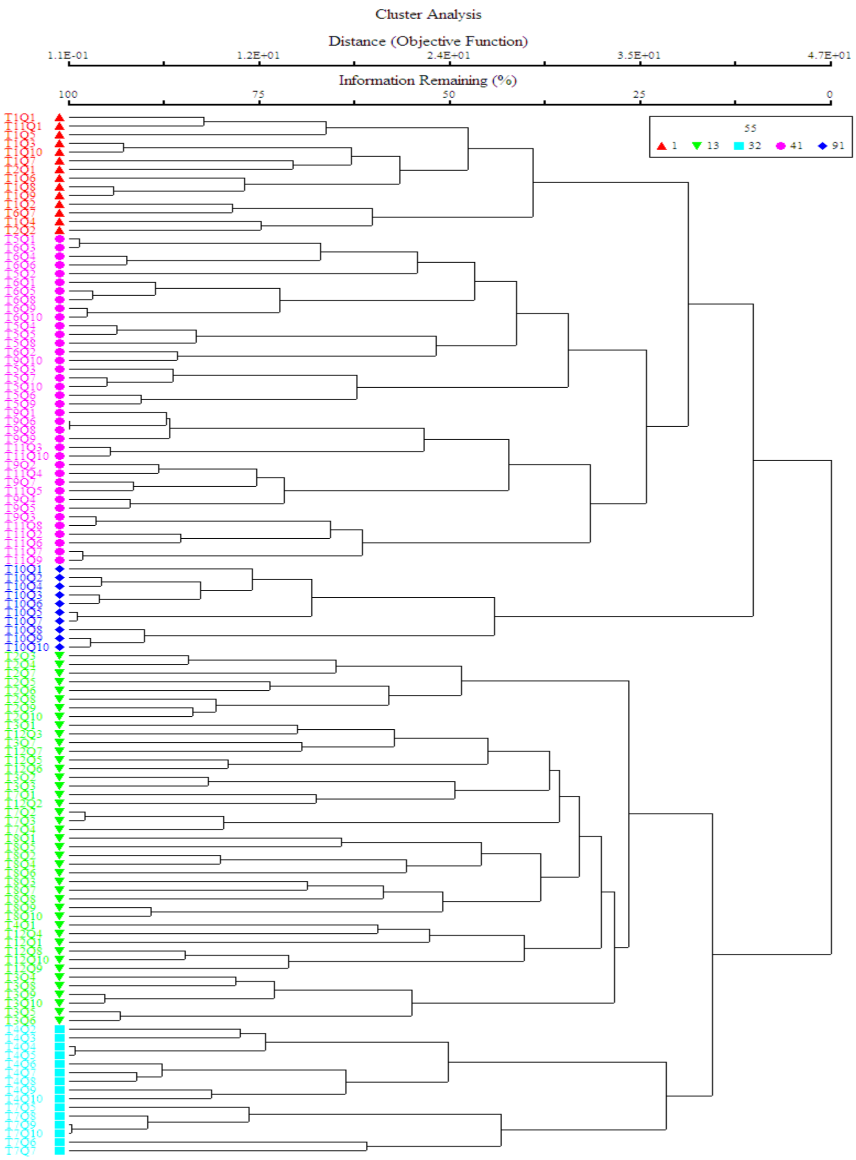


***Figure 4.*** *Cluster Analysis dendrogram representing all the stations into 5 plant associations*


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*Association-1 (Acacia-Ziziphus-Asphodelous association)*

A total of 163 species of 4 different stations were clustered in this association. This association was developed in plain landscape at 430 - 675 m altitude. The topmost indicator species of this association were *Acacia nilotica, Ziziphus nummularia* and *Asphodelous tenuifolius* after the indicator species analysis (ISA) (*Fig. 5; Table 2*). The important environmental variables responsible for establishment this association were low pH and high amount of sand and phosphorous. Other characteristic herb species of this association were *Centaurea iberica*, *Malvastrum coromandelianum*, *Dactyloctenium aegyptium*, *Euphorbia prostrata* and *Cyperus rotundus*. The abundant shrub species of this association included *Lantana camara*, *Prosopis cineraria* and *Calotropis procera* while *Acacia nilotica* and *Melia azedarach* were the dominant tree species in the region.

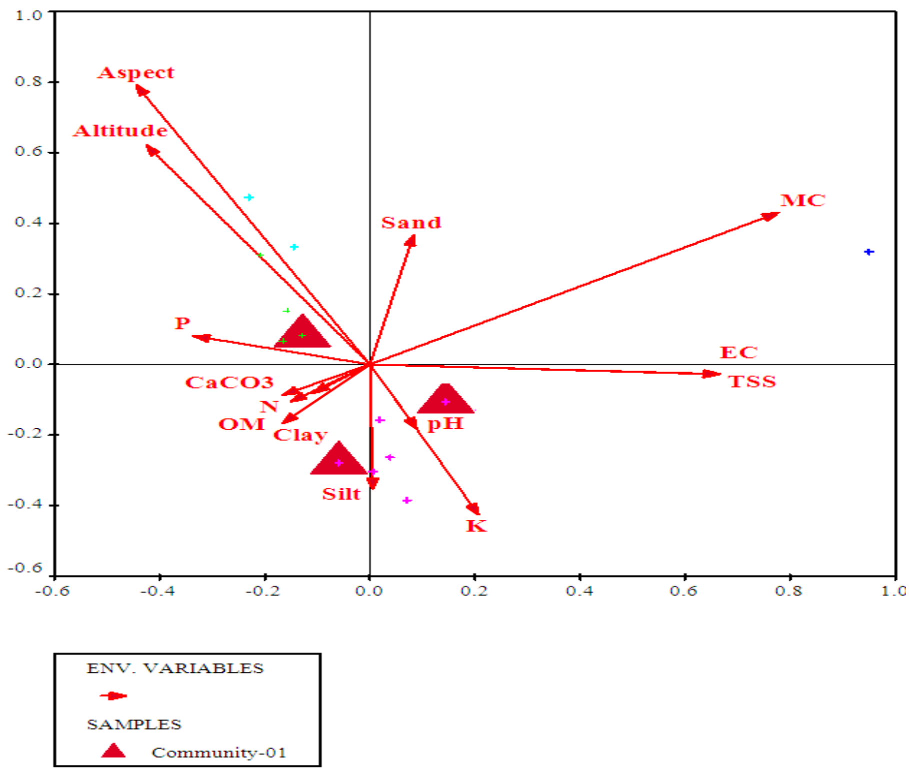


***Figure 5.*** *Data attribute plot of Acacia nilotica (tree indicator species) of association-1 in relation to measured environmental variables*

Soil analyses of this association contained sand (52-58%), silt (36-44%), clay (2-4%) with pH ranged from 8.0 to 8.5, EC (0.11-0.20 dsm$^{-1}$), moisture (5.3-6.5%), TSS (0.035-0.064%), $CaCO_3$ (6.75-8.25%), OM (0.65-0.79%), N (0.032-0.039 mg kg$^{-1}$), P (8.0-15.4 mg kg$^{-1}$) and K (90-120 mg kg$^{-1}$) (*Table 3*).

*Association-2 (Morus-Saccharum-Phalaris association)*

A total of 197 plants, near to cultivated lands at altitude range of 430-800 m of 4 different stations clustered in this association. The top indicator species included *Morus nigra*, *Saccharum bengalense* and *Phalaris minor* after the ISA (*Fig. 6; Table 2*). The primary determinant environmental variables responsible for the formation of this


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association were low pH and high amount of $CaCO_3$ and clay. *Silybum marianum*, *Euphorbia helioscopia*, *Galium aparine*, *Parthenium hysterophorus*, *Achyranthes aspera*, *Torilis leptophylla*, *Poa annua*, *Digitaria sanguinalis*, *Cannabis sativa* and *Brachiaria ramosa* were the dominant herb species of this association. The important shrubs included *Dodonaea viscosa*, *Justicia adhatoda*, *Calotropis procera*, *Zizipus numularia*, and *Rosa multiflora* while *Broussonetia papyrifera*, *Melia azedarach*, *Populus nigra* and *Morus alba* were important tree species.

***Table 2.*** *The topmost indicator species of each association, based on indicator species analysis (ISA)*

| Associations | Indicator species | Variables | MONTE CARLO test of significance (using ISA) | | |
|---|---|---|---|---|---|
| | | | Max. grp | IV | P* Values |
| Association-1 | 1. *Acacia nilotica* | pH | 7 | 41.2 | 0.0462 |
| | *2. Ziziphus nummularia* | Sand | 54 | 41.2 | 0.0004 |
| | 3. *Asphodelous tenuifolius* | Phosphorus | 15 | 60 | 0.0002 |
| Association-2 | 1. *Morus nigra* | pH | 7 | 60.7 | 0.0012 |
| | 2. *Saccharum bengalense* | Clay | 10 | 34.5 | 0.0005 |
| | 3. *Phalaris minor* | $CaCO_3$ | 9 | 85.3 | 0.0002 |
| Association-3 | 1. *Salix acmophylla* | Moisture | 20 | 30 | 0.0026 |
| | 2. *Debregeasia salicifolia* | Moisture | 20 | 31.2 | 0.0012 |
| | 3. *Agrostis viridis* | Moisture | 20 | 100 | 0.0002 |
| Association-4 | 1. *Monotheca buxifolia* | Altitude | 73 | 56.2 | 0.0002 |
| | 2. *Rhazya stricta* | Phosphorus | 19 | 32.5 | 0.0054 |
| | 3. *Aerva javanica* | Aspect (S) | 2 | 42.3 | 0.0002 |
| Association-5 | 1. *Phoenix sylvestris* | Aspect (N) | 3 | 43.7 | 0.0114 |
| | 2. *Myrsine africana* | Aspect (N) | 3 | 50.2 | 0.001 |
| | 3. *Viola canescens* | Altitude | 105 | 33.6 | 0.0012 |

***Table 3.*** *Physicochemical properties of soil of each association in the sub-tropical zone of Hindu Kush Mountain range*

| Associations | pH | EC | Clay | Silt | Sand | MC | $CaCO_3$ | OM | TSS | N | P | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ($dsm^{-1}$) | --------------------------------%----------------------------------- | | | | | | | | (mg $^{-kg}$) ----- | |
| 1 | 8.0-8.5 | 0.11-0.20 | 2-6 | 36-44 | 52-58 | 4.2-6.5 | 6.8-8.3 | 0.65-0.79 | 0.035-0.064 | 0.032-0.039 | 5.7-15.4 | 90-120 |
| 2 | 7.9-8.5 | 0.10-0.20 | 4-10 | 36-44 | 48-58 | 4.59.1 | 7.5-9.0 | 0.69-0.86 | 0.032-0.064 | 0.034-0.043 | 5.7-14.8 | 90-140 |
| 3 | 8.1 | 0.20 | 2 | 38 | 60 | 20.9 | 7.5 | 0.69 | 0.064 | 0.034 | 4 | 110 |
| 4 | 8.0-8.1 | 0.11 | 2-8 | 36-40 | 48-60 | 4.2-12.5 | 6.8-10.0 | 0.65-0.86 | 0.035-0.038 | 0.034-0.043 | 2.2-22.8 | 96-120 |
| 5 | 8.0 | 0.11 | 2-8 | 38-44 | 48-60 | 6.8-13 | 6.8-8.8 | 0.69-0.86 | 0.035 | 0.034-0.043 | 2.2-22.8 | 98-110 |


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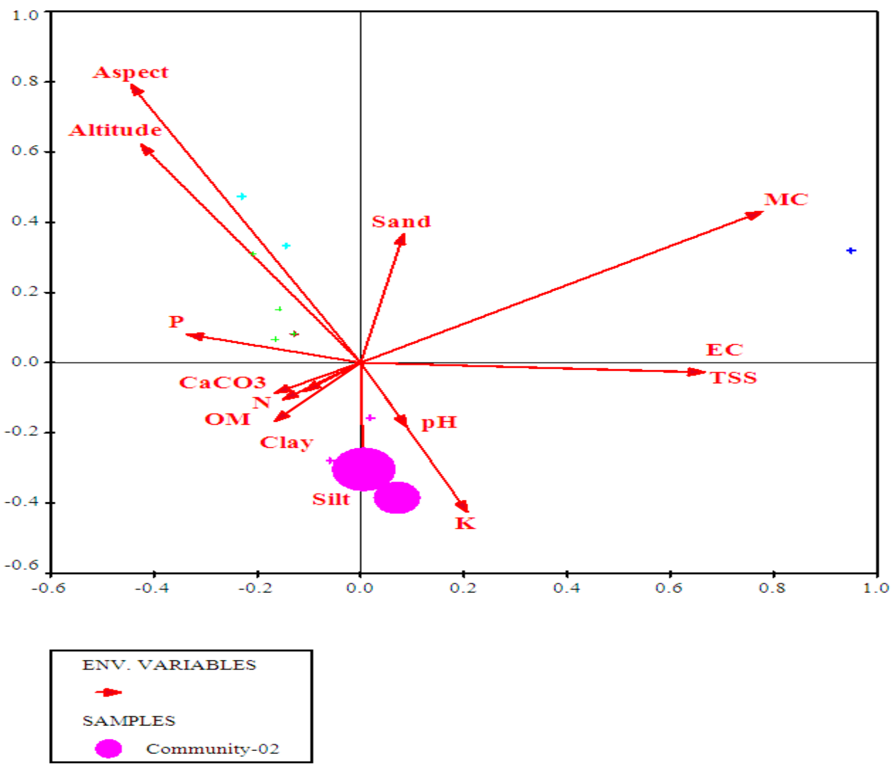


***Figure 6.** Data attribute plot of Saccharum bengalense (shrub indicator species) of association-2 in relation to measured environmental variables*

This association was formed in alkaline soil having pH range from 7.9-8.5. The soil texture contained 8-58% sand, 36-44% silt and 4-10% clay with 4.5-9.1% moisture. EC varied from 0.10-0.20 dsm$^{-1}$, TSS 0.032-0.064%, $CaCO_3$ 7.5-9.0%, OM 0.69-0.86%, N 0.039-0.043 mg kg$^{-1}$, P 5.7-14.8 mg kg$^{-1}$, and K 90-140 mg kg$^{-1}$ (*Table 3*).

*Association-3 (Salix-Debregeasia-Agrostis association)*

In streambeds at altitude of 463-520 m, a total of 89 plants belonging to single station clustered in this association. The ISA inveterate *Salix acmophylla*, *Debregeasia salicifolia* and *Agrostis viridis* as top indicators of this association showing their affinities with higher moisture contents (20.9%) (*Fig. 7; Table 2*). *Leucaena leucocephala*, *Eucalyptus camaldulensis*, *Broussonetia papyrifera* and *Ailanthus altissima* among trees while *Arundo donax*, *Debregeasia salicifolia*, *Saccharum ravennae Vitex negundo*, and *Nerium oleander* among shrubs were the dominant plant species. The herbaceous layer was dominated by *Nasturtium officinale*, *Persicaria maculosa*, *Paspalum paspaloides*, *Mentha longifolia*, *Arundo donax*, *Saccharum filifolium*, *Alternanthera sessilis*, *Persicaria hydropiper*, *Alopecurus myosuroides*, *Alternanthera philoxeroides*, *Cyperus alopecuroides*, *Kyllinga brevifolia* and *Ranunculus sceleratus*.

Soil texture of this association comprised of 60% sand, 38% silt and 2% clay with the highest amount of moisture contents (20.9%). The other soil variables included EC 0.20 dsm$^{-1}$, pH 8.1, TSS 0.064%, $CaCO_3$ 7.50%, OM 0.69%, N 0.034 mg kg$^{-1}$, P 4.0 mg kg$^{-1}$ and K 110 mg kg$^{-1}$ (*Table 3*).

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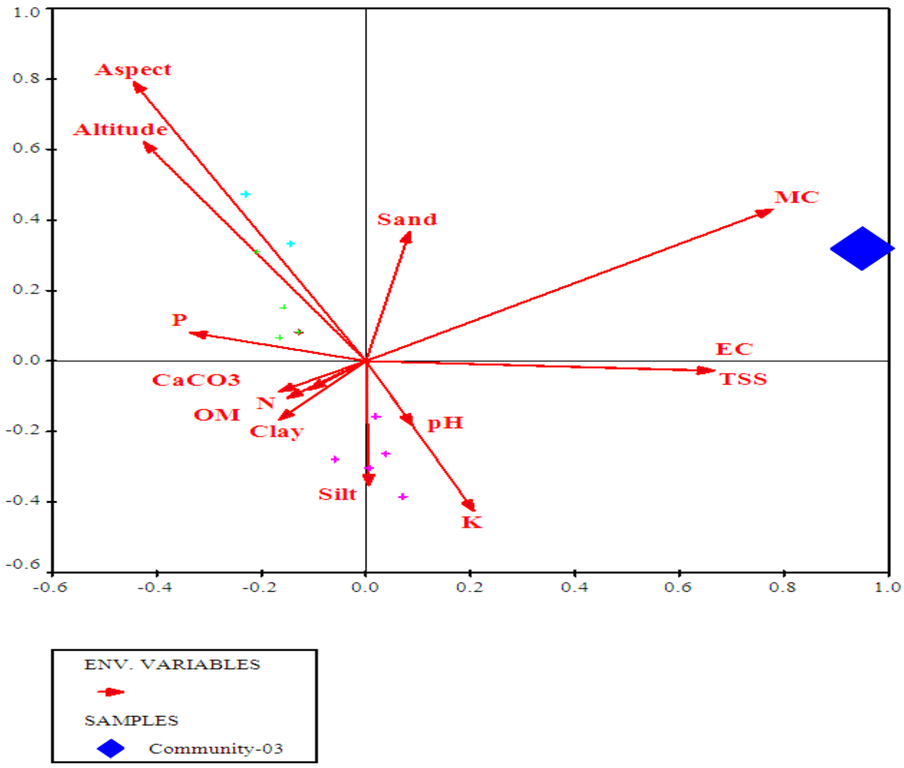


***Figure 7.*** *Data attribute plot of Agrostis viridis (herb indicator species) of association-3 in relation to measured environmental variables*

*Association-4 (Monotheca-Rhazya-Aerva association)*

This association comprised a total of 243 plants, distributed in 6 different stations. This association was established in hilly landscape at 496-1072 m elevation at south aspect. The foremost indicator species were *Monotheca buxifolia*, *Rhazya stricta* and *Aerva javanica* (*Fig. 8; Table 2*). The indicator species of this association were influenced by altitude (higher), aspect (south) and high amount of phosphorous. These were the indicators of south aspect and lower altitude. Other important herb species included *Micromeria biflora*, *Arenaria serpyllifolia*, *Medicago minima*, *Cynodon dactylon*, *Lactuca dissecta*, *Ajuga bracteosa*, while in shrubs *Dodonaea viscosa* and *Justicia adhatoda* were the dominant shrubs. The other important tree species were *Acacia modesta* and *Olea ferruginea*.

Soil texture of this association contained 48-64% sand, 32-40% silt and 2-8% clay with 4.2-12.5% moisture. The soil pH varied from 8.0-8.1, EC 0.11-0.12 $dsm^{-1}$, TSS 0.035-0.038%, $CaCO_3$ 6.75-10.0%, OM 0.69-0.86%, N 0.032-0.043 mg $kg^{-1}$, P 2.2-22.8 mg $kg^{-1}$ and K 95-120 mg $kg^{-1}$ (*Table 3*).

*Association-5 (Phoenix-Myrsine-Viola association)*

This association comprised of 143 species, distributed in 2 stations. This association was formed at higher altitude (690-1072 m) at north aspect. *Phoenix sylvestris Myrsine africana* and *Viola canescens* were the indicator species of association-5 (*Fig. 9; Table 2*), showing its affinity with high altitude and north aspect. The dominant herb species included *Origanum vulgare*, *Scilla griffithii*, *Heteropogon contortus*, *Arabidopsis*


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*thaliana*, *Gagea elegans*, *Chrysopogon aucheri*, *Lespedeza juncea*, *Tulipa clusiana* while *Rubus fruticosus* and *Pinus roxburghii* were dominant shrub and tree species, respectively.

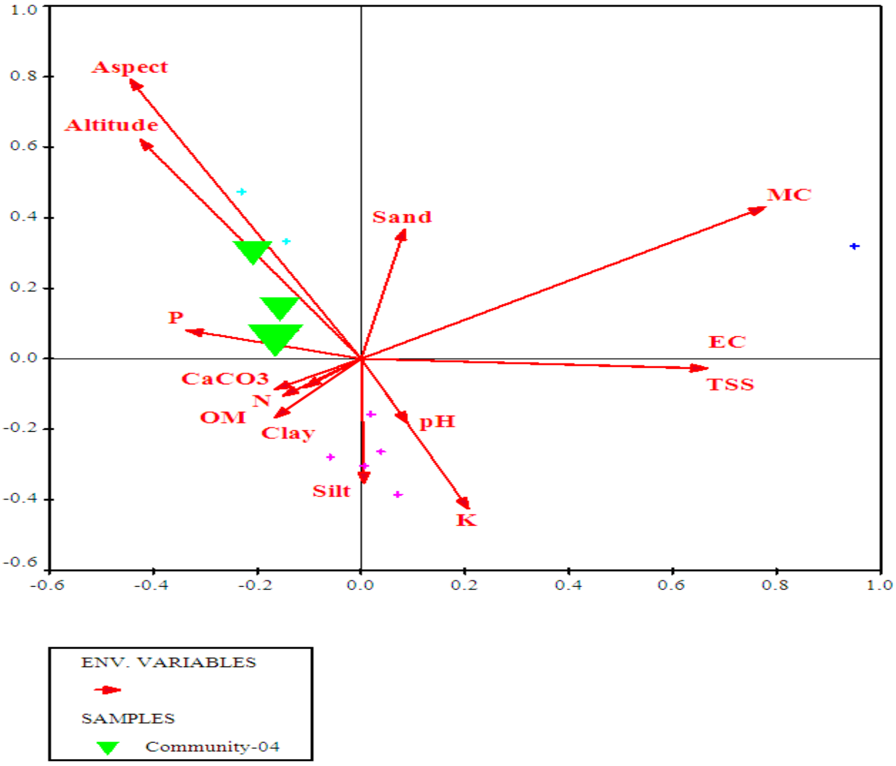


***Figure 8.** Data attribute plot of Rhazya stricta (shrub indicator species) of association-4 in relation to measured environmental variables*

The soil texture of this association contained 48-60% sand, 38-44% silt and 2-8% clay, along with 6.8-12.5% moisture. The other soil features included 8.0 pH, 0.11 $dsm^{-1}$ EC 0.035% TSS, 6.75-8.75% $CaCO_3$, 0.69-0.86% OM, 0.034-0.43 mg $kg^{-1}$ N, 2.2-22.8 mg $kg^{-1}$ P and 98-110 mg $kg^{-1}$ K (*Table 3*).

### *Detrended Correspondence Analysis (DCA) of stations*

DCA ordination tells about the pattern in complex data set. DCA was used to analyze the ordination of samples. The Eigen values for axis 1, 2, 3 and 4 were 0.619, 0.312, 0.246 and 0.198, respectively. The explained variations (cumulative) for the same axis were 5.7, 8.6, 10.9 and 12.7. The gradient length for axis 1, 2, 3 and 4 were 5.299, 3.300, 3.108 and 2.128, respectively (*Table 4*). DCA confirmed the plant association classified by CA. In DCA diagram, association-1 and association-2 occupied the center of the DCA diagram, having a partial overlapping of association-1 over association-2 because of the same topographic features and lower altitude. Association-3 clustered a distinct group on the right-hand side of the DCA diagram because of high moisture contents of soil (20.9%). Association-4 ordinated a separate group at lower left of DCA plot. The driving ecological factors for the clustering of this diverse group are aspect (south), similar low moisture contents (4.5-5.9%) and altitude.  While plant species of higher altitude at north aspect were clustered in the top-left of the graph forming associations 5 (*Fig. 10*).


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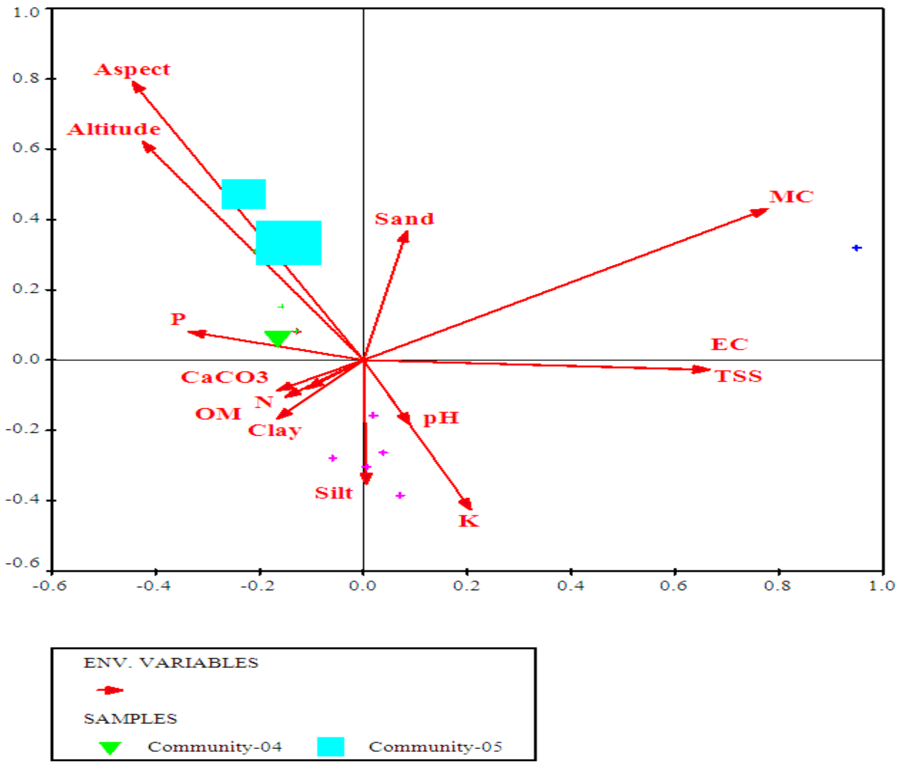


***Figure 9.** Data attribute plot of Viola canescens (herb indicator species) of association-5 in relation to measured environmental variables*

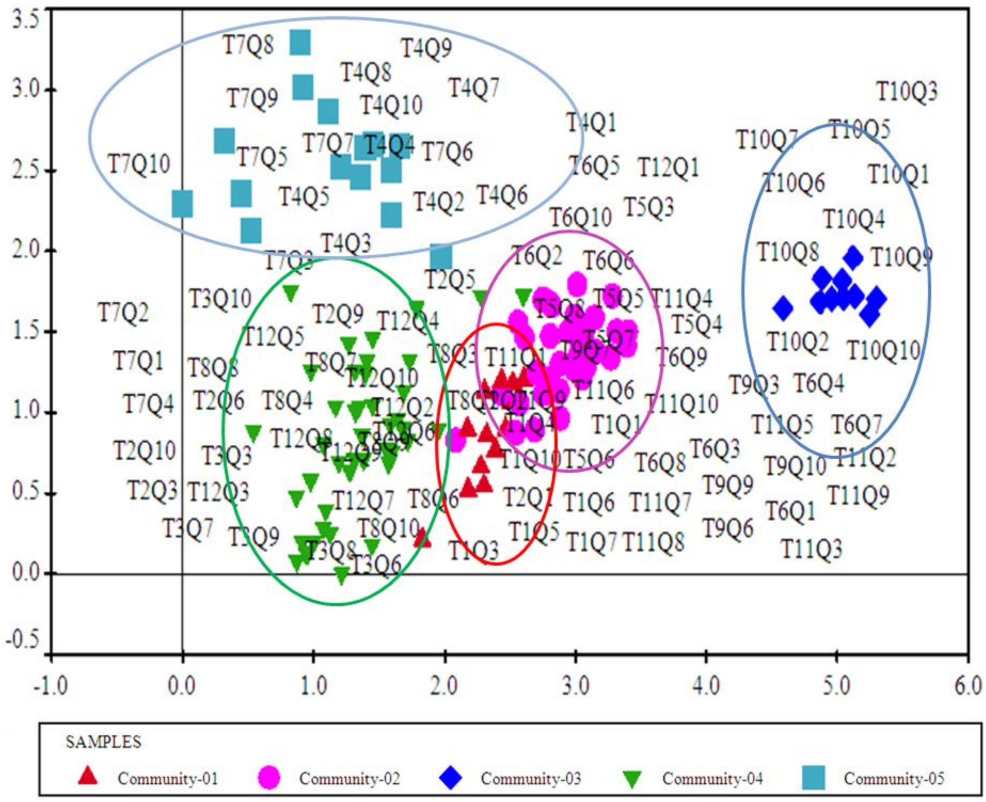


***Figure 10.** DCA ordination plot of different stations in the study area*


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***Table 4.*** *Description of the four axes of DCA ordination plot of different stations*

| **Axes** | **1** | **2** | **3** | **4** | **Total inertia** |
|---|---|---|---|---|---|
| Eigen values | 0.619 | 0.312 | 0.246 | 0.198 | 10.823 |
| Lengths of gradient | 5.299 | 3.300 | 3.108 | 2.128 | |
| Cumulative percentage variance of species data | 5.7 | 8.6 | 10.9 | 12.7 | |

### *Canonical Correspondence Analysis (CCA) of stations*

In CCA ordination the maximum eigen value (0.600) was recorded for axis 1, followed by axis 2 (0.472), axis 3 (0.318) and axis 4 (0.231). Species-environment correlation was 0.987, 0.963, 0.919 and 0.931 for axis 1, 2, 3 and 4, respectively. Cumulative percentage variance of species data was 5.5, 9.9, 12.8 and 15.0 for axis 1, 2, 3 and 4 respectively. Species-environment relation for axis 1, 2, 3 and 4 was 23.9, 42.7, 55.4 and 64.6, respectively. The permutation test results for all axis were F (3.292) and P (0.0020) (*Table 5*).

***Table 5.*** *Description of the four axes of the CCA for stations*

| **Axes** | **1** | **2** | **3** | **4** | **Total inertia** |
|---|---|---|---|---|---|
| *Eigen values* | *0.600* | *0.472* | *0.318* | *0.231* | *10.823* |
| Species-environment correlation | 0.987 | 0.963 | 0.919 | 0.931 | |
| Cumulative percentage variance of species data | 5.5 | 9.9 | 12.8 | 15.0 | |
| Species-environment relation | 23.9 | 42.7 | 55.4 | 64.6 | |
| Sum of all eigenvalues | | | | | 10.823 |
| Sum of all canonical eigen values | | | | | 2.510 |
| Summary of Monte Carlo test (499 permutations under reduced model) | | | | | |
| Test of significance of first canonical axis | | Test of significance of all canonical axes | | | |
| Eigen value | 0.600 | Trace | 2.510 | | |
| F-ratio | 6.398 | F-ratio | 3.292 | | |
| P-value | 0.0020 | P-value | 0.0020 | | |

The CCA bi-plot of stations (*Fig. 11*) showed that altitude, aspect and moisture contents were the strongest variable amongst the ecological factors. Moisture contents showed their strongest influence at first quadrant and strongly effected the vegetation at station-10 (high moisture contents), station-8 and station-2 (lower moisture contents). Altitude and aspect strongly influence the vegetation at station-4, station-7 (high altitude, north aspect), station-3, station-8 and station-12, (lower altitude, south aspect) at second quadrant. The 3$^{rd}$ and 4$^{th}$ quadrant showed the effect of different edaphic factors in the plains of the study area. The edaphic factors like calcium carbonate, organic matter, nitrogen and clayey nature of soil showed its effect at station-1 while pH, TSS, K showed their effects at stations 5, 6 and 9.


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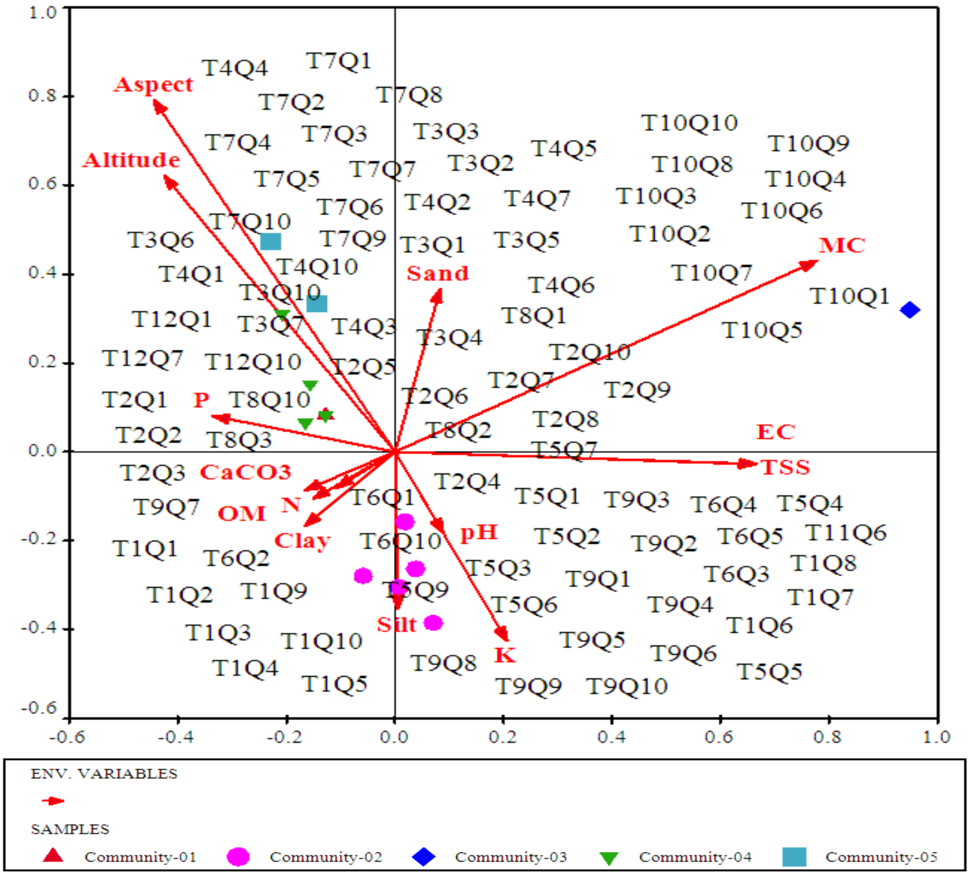


***Figure 11.*** *CCA ordination plot the effect of environmental variables and sampled stations*

### *Canonical Correspondence Analysis (CCA) of herb species*

CCA indicated that most of the plants were accumulated under the influence of moisture contents and sandy nature of soil. The species like *Oenothera rosea*, *Cheilanthes acrostica*, *Erioscirpus comosus*, *Alopecurus myosuroides*, *Paspalum paspaloides*, *Saccharum filifolium*, *Nasturtium officinale*, *Pycreus flavidus*, *Asplenium incisum*, *Mentha longifolia* and *Bidens tripartita* were affected by moisture contents. Species like *Cymbopogon jwarancusa*, *Conyza canadensis*, *Conyza bonariensis*, *Cerastium glomeratum*, *Boerhavia procumbens*, *Kickxia ramosissima*, *Forsskaolea tenacissima*, *Gagea elegans*, *Anisomeles indica*, *Scilla griffithii*, *Launaea procumbens*, *Lindenbergia indica*, *Teucrium stocksianum*, *Aerva sanguinolenta*, *Fagonia indica*, *Phagnalon niveum*, *Artemisia scoparia* and *Ajuga bracteosa* revealed their affinity to sandy nature of soil. *Chrysopogon aucheri*, *Heteropogon contortus*, *Aristida cyanantha*, *Micromeria biflora* and *Salvia aegyptiaca* were grouped under the influence of north aspect, higher altitude and phosphorous. Species like *Aerva javanica*, *Chenopodium botrys*, *Erodium malacoides*, *Triumfetta pentandra*, *Salvia aegyptica* showed their preference for lower altitude and south aspect.  Phosphorous effected the distribution of *Plantago amplexicaulis* and *Sisymbrium irio*. Most of the species grouped around $CaCO_3$, N, OM, clayey and silty nature of soil. The existence of *Anagallis arvensis*, *Scandix pecten-veneris*, *Citrullus lanatus*, *Veronica biloba*, *Casia occidentalis Thymelaea passerina*, *Vicia sativa*, *Salvia moocroftiana*, *Parthenium hysterophorus*, *Chenopodium murale*, *Acrachne racemosa*, *Dichanthium annulatum*, *Raphanus raphanistrum* and *Cirsium*


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*arvense* depicted their affinity to $CaCO_3$, OM, N, clay and silt. *Filago hurdwarica, Atylosia scarabaeoides, Ranunculus muricatus, Cannabis sativa, Galium aparine, Xanthium strumarium, Rumex dentatus, Amaranthus graecizans, Euphorbia heterophylla, Lathyrus aphaca, Chenopodium album, Ipomoea pes-tigridis, Malvastrum coromandelianum, Lactuca serriola, Phalaris minor, Achyranthes aspera, Convolvulus arvensis, Setaria pumila, Imperata cylindrica, Ipomoea nil, Chrozophora tinctoria, Sorghum halepense, Coronopus didymus* and *Euphorbia helioscopia* showed their ecological amplitude with pH, TSS, K and EC (*Fig. 12*).

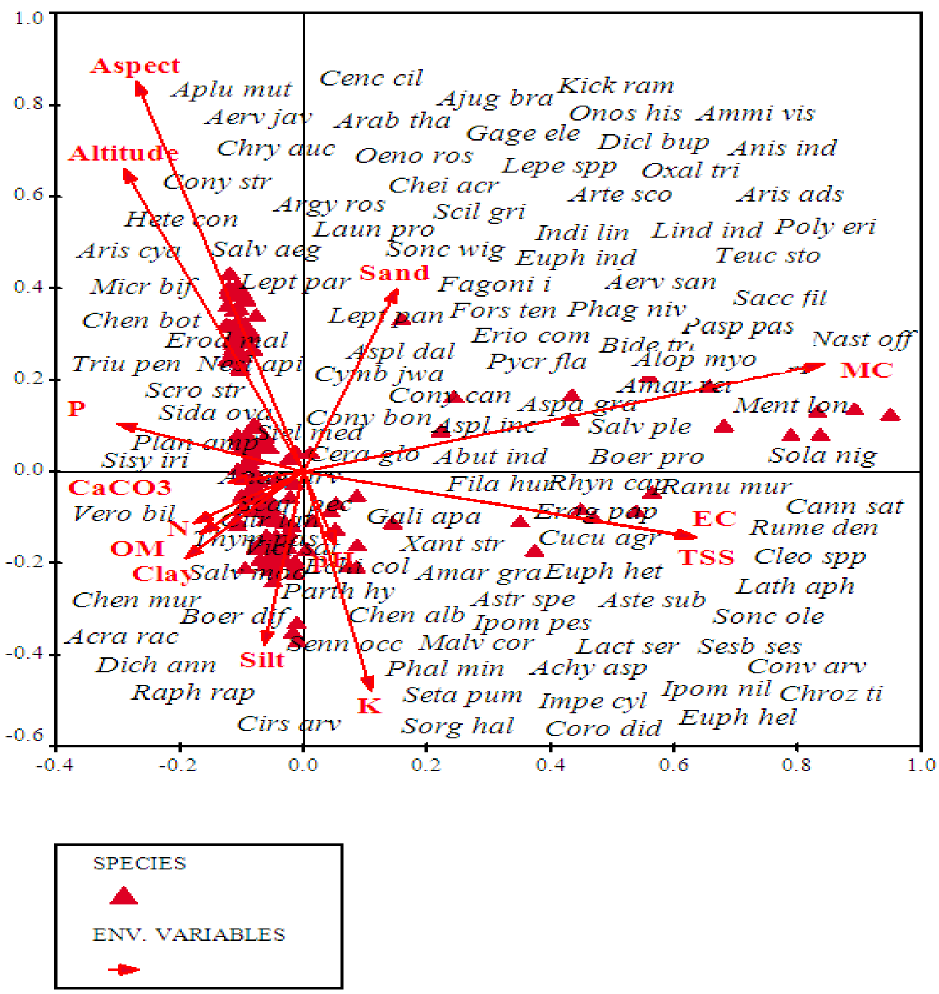


***Figure 12.*** *CCA plot showing the distribution of herbs under the influence of environmental variables*

### *Canonical Correspondence Analysis (CCA) of shrubs and trees*

CCA of shrubs and trees (Fig. 12) showed that altitude, aspect and moisture contents were the strong influencing factors among the environmental variables. The CCA showed that the aspect, altitude, organic matter, N and clayey nature of the soil influenced *Pinus roxburghii, Himalrandia tetrasperma, Rubus fruticosus, Daphne mucronata, Periploca aphylla, Ziziphus oxyphylla, Isodon rugosus* and *Mallotus phillipensis.* While *Phoenix sylvestris, Ficus racemosa, Olea ferruginea* and *Platanus orientalis* were associated with OM, N, P and clayey nature of soil. Soil moisture, electrical conductivity, K, TSS and


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silty nature of soil affected *Debregeasia salicifolia*, *Saccharum ravennae* and *Rosa multiflora plant* species distribution. Silt influenced the distribution of *Ricinus communis*, *Ailanthus altissima* and *Robinia pseudo-acacia. Morus nigra* and *Eucalyptus camaldulensis* showed their affinity with EC, TSS and K. Furthermore, the distribution of *Dalbergia sissoo*, *Ziziphus nummularia*, *Acacia nilotica* and *Parkinsonia aculeata* were influenced by soil pH in the region. While *Nerium oleander*, *Withania somnifera*, *Calotropis procera* and *Ziziphus mauritiana* showed correlation with pH and $CaCO_3$. Similarly, *Rhazya stricta*, *Maytenus royleanus*, *Saccharum griffithii*, *Justicia adhatoda*, *Cissampelos pareira*, *Berberis lycium*, *Colebrookea oppositifolia*, *Otostegia limbata*, *Woodfordia fruticosa*, *Albizia lebbeck*, *Ficus bengalensis* and *Tecomella undulata* were associated with sandy nature of soil (Fig. 13).

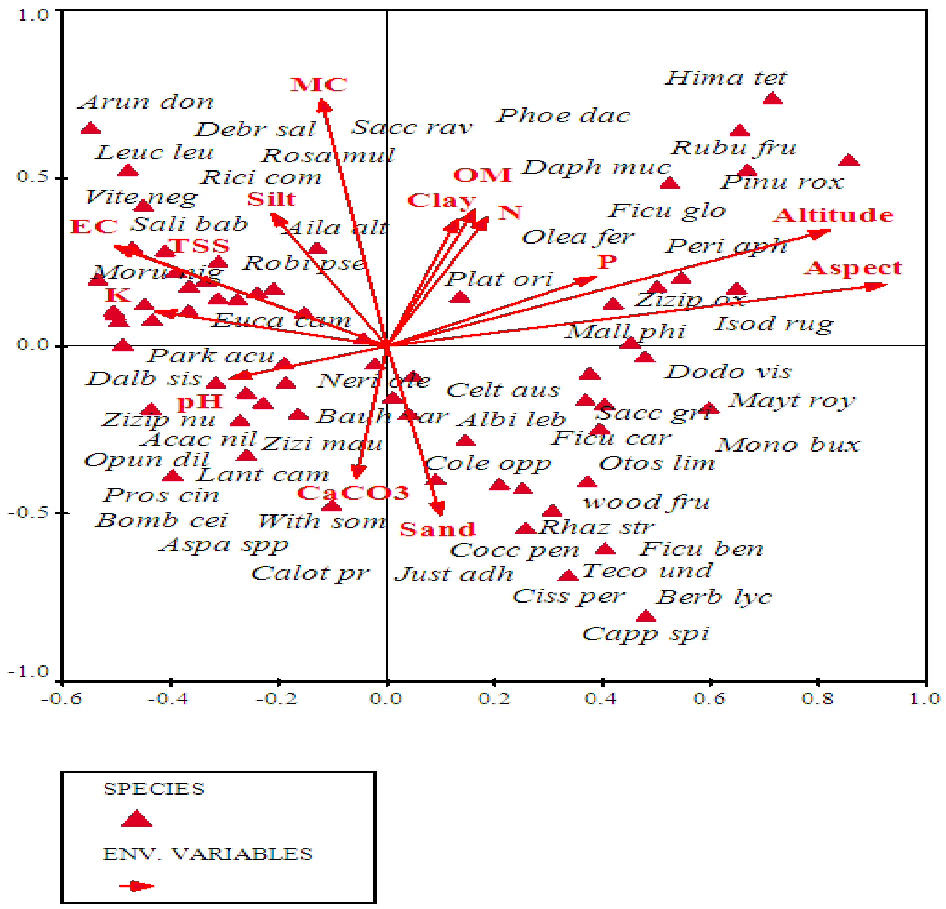


***Figure 13.*** *CCA plot showing the distribution of shrubs and trees under the influence of environmental variables*

## Discussion

The distribution pattern and composition of plants are usually attributed to edaphic and environmental factors. This research study indicated that the environmental variables significantly impact vegetation structure/dynamics and hence plant associations changed in response to different environmental gradients. In the current study, 382 species belonging to 289 genera of 91 families were recognized. The flora included a high number of herbaceous species (290 sp., 76%). It was followed by shrubs having 46 species (12%),


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trees 39 species (10%) and shrubby climbers 7 species (2%). The present results are similar to the previous studies (Shuaib et al., 2014; Qureshi et al., 2014) thus strengthening the present results.

The present study revealed that Poaceae (with 48 species), Asteraceae (sp., 34), Papilionaceae (sp., 24), Lamiaceae (sp., 17), Brassicaceae (sp., 15), Amaranthaceae (sp., 13), Boraginaceae (sp., 13), Euphorbiaceae (sp., 11), Scrophulariaceae (sp., 11) and Cyperaceae (sp., 10) were the most diverse families. As the families like Poaceae, Asteraceae, Lamiaceae and Brassicaceae are diverse due to their wide ecological amplitude, they are also dominant in the current area. Our findings are in line with Ilyas et al. (2013), Amjad et al. (2013), Saleem et al. (2013) and Qureshi et al. (2014) who also described Poaceae and Asteraceae as the leading families. Similarly, Jafari and Akhani (2008) reported Poaceae and Lamiaceae as the largest families in their study.

Life form spectrum of vegetation of the studied area disclosed that therophytes (169 sp., 44.2%) followed by hemicryptophytes (81 sp., 21.2%) and nanophanerophytes (39 sp.,10.2%) were the dominant leaf size classes. The other leaf size classes included chamaephytes (24 sp., 6.3%), mesophanerophytes (20 sp., 5.2%), megaphanerophytes (18 sp., 4.7%) and geophytes (18 sp., 4.7%) and microphanerophytes (13 sp., 3.4%). The dominancy of therophytes and hemicryptophytes were also noted by Tripathy et al. (2013), Badshah et al. (2013) and Hussain et al. (2015). The presence of a greater number of therophytes may respond to anthropogenic pressure and the harsh climate (Qureshi et al., 2011; Shahid and Joshi, 2015) because therophytes are better adapted to dry climate (Shah, 2013).

The results of biological spectrum revealed that the leaf size spectrum was dominated by microphylls (185 sp., 48.4%) followed by nanophylls (107 sp., 28.0%) and mesophylls (61 sp., 16.0%). The other leaf size classes were leptophylls (21 sp., 5.5%) megaphylls (4 sp., 1.0%) and aphyllous (4 sp., 1.0%). The presence of a greater number of microphylls and nanophylls may respond to anthropogenic pressure and the harsh climate because such species are better adapted to dry climate. Such type of results has been found by several workers. Haq et al. (2015) found microphylls as the dominant leaf size class while studying vegetation of subtropical forests in Battagram District. Sharma and Sharma (2020) also revealed microphyllous type of vegetation followed by nanophylls. In the study of Khan et al. (2016), microphylls, followed by leptophylls and nanophylls species were dominant. Similarly, in the study of Ullah and Badshah (2017) the leading leaf size classes were microphylls and nanophylls.

The CA clustered all the stations and plant species into 5 main associations and their distinctive indicators. In *Acacia-Ziziphus-Asphodelous* association (Association-1) a total of 163 species of 4 different stations were clustered. This association was developed in the plain landscape at 430 - 675 m altitude. The topmost indicator species of this association were *Acacia nilotica*, *Ziziphus nummularia* and *Asphodelous tenuifolius*. The important environmental variables responsible for establishment of this association were low pH, greater amount of sand and high quantity of phosphorous. A total of 197 plants clustered in *Morus-Saccharum-Phalaris* association (Association-2). The top indicator species included *Morus nigra*, *Saccharum bengalense* and *Phalaris minor*. This association was developed in the plain landscape at 430 - 800 m altitude. The primary determinant environmental variables, responsible for the formation of this association were low pH, high amount of clay and $CaCO_3$. A total of 89 plants clustered in *Salix-Debregeasia-Agrostis* association (Association-3) at altitude of 463-520 m. The ISA inveterate *Salix acmophylla*, *Debregeasia salicifolia* and *Agrostis viridis* as top indicator


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species of this association under the influence of higher moisture contents (20.9%). *Monotheca-Rhazya-Aerva* association (Association-4) comprised a total of 243 plants, distributed in 6 different stations. This association was established in higher altitude hills at 496-1072 m elevation at south aspect. The foremost indicator species were *Monotheca buxifolia*, *Rhazya stricta* and *Aerva javanica*. These were the indicators of south aspect and lower altitude. The indicator species of this association were influenced by high altitude, aspect (south) and high amount of phosphorous. *Phoenix-Myrsine-Viola* association (Association-5) comprised of 143 species, distributed in 2 stations. This association was formed at higher altitude (690-1072 m) at north aspect. *Phoenix sylvestris Myrsine africana* and *Viola canescens* were the indicator species with high altitude and north aspect.

Plant species are restricted to specific habitats due to the presence of optimum environmental factors. In the present study, five plant communities were established by using Cluster analysis (CA) and Two-Way Cluster Analysis (TWCA), which are same to the previous studies of Ahmad et al. (2016), Iqbal et al. (2017) and Khan et al. (2017b). They all found 5 various plant communities in their respective studied areas by using CA and TWCA. It is essential to know the environmental determinants of species (Rahman et al., 2021). Hence, in this study, vegetation was correlated with ecological variables using CCA. The environmental gradients (altitude, aspect, sand, silt, clay, pH, EC, MC, CaCO3, OM, N, TSS, P, K) showed significant effect on species distribution. Such impacts have also been studied by numbers of researchers (Khan et al., 2016, 2017 a, b; Anwar et al., 2019).

DCA ordination tells about the pattern in complex data set. DCA was used to analyze the ordination of stations. A DCA diagram of stations revealed the position of different stations along the axes and their association with the gradients. DCA resulted five distinct associations in the study area. The plant association classified by CA were confirmed by DCA. In DCA diagram, association-1 and association-2 occupied the center of the DCA diagram, having a partial overlapping of association-1 over association-2 because of the same topographic features and lower altitude. Association-3 clustered as a distinct group in the right-hand side of the DCA diagram because of high moisture contents of soil (20.9%). Association-4 ordinated a separate group at lower left of DCA plot. The driving ecological factors for the clustering of this diverse group are aspect (south), similar low moisture contents (4.5-5.9%) and altitude. While in association-5, plant species of higher elevation at north aspect were clustered in the top-left of the graph. In ecological terms, plant species of plain areas at lower altitudes are clustered in the middle of the graph (associations-1 & 2). Species of moist or aquatic environment are present at the right side in association-3. Plant species of south aspect with lower moisture were clustered in the lower-right of the graph (associations-4). Plant species of higher elevation at north aspect were clustered in in associations-5 at the top-left of the DCA diagram. The present DCA analysis strongly supporting the CCA results by revealing the same ecological factors like altitude, aspect, topography and edaphic characteristics are responsible for distribution of plants in various habitats in research area. The results of the present DCA analysis are similar with the results of Naqinezhad et al. (2008), Jabeen and Ahmed (2009) and Khan et al. (2017 b) as they also indicated the same ecological factors as the strong drivers for the distribution and composition of vegetation structure. CCA explains the relationship of measured environmental variables on species composition and distribution pattern. The tested environmental variables in the present study were altitude, aspect, clay, sand, silt, pH, moisture contents, electrical conductivity, organic matter, phosphorous, potassium,


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nitrogen and total soluble salts showed significant effect on plant species distribution of the region. Such impacts were also being study by numbers of authors in the neighboring habitats of Pakistan. In addition, any change in environmental variables and altitude cause significant effect in formation of communities (Dhyani et al., 2019; Manan et al., 2020; Rawat et al., 2020; Tiwari et al., 2020; Karami et al., 2021; Zeeshan et al., 2021).

## Conclusion

It is concluded that the studied area is rich in term of species diversity. As a whole 382 species belonging to 289 genera of 91 families were recorded. Based on habit, maximum species were herbs, followed by shrubs, trees and shrubby climbers. The top leading families were Poaceae, Asteraceae, Papilionaceae, Lamiaceae and Brassicaceae. Biological spectrum showed that therophytes followed by hemicryptophytes and nanophanerophytes were the dominant life form classes while microphylls followed by nanophylls and mesophylls were the dominant leaf size classes. The quantitative data of plant species was further subjected to find out the effect of various edaphic and topographic variables, responsible for vegetation structure and species distribution. CA and resulted in five plant associations. DCA results further clarified five clusters revealing five types of association in the study area. CCA results revealed that several topographic and edaphic factors altitude, aspect, clay, silt, sand, moisture, pH, EC, TSS, organic matter, $CaCO_3$, N, P and K significantly influenced species distribution and vegetation structure. As the present study also highlights the severe biotic pressure on the vegetation as is evidenced by the presence of greater number of therophytes and microphyllous species in the study area. Hence, the biotic influences on the vegetation entails assessment to plan suitable measures for the conservation of all species in general and indicator and rare species in particular.

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