

Full Length Article

Ecological Importance of Physiognomic Characteristics of Floral Biodiversity along the Karakoram Highway, Gilgit-Baltistan Pakistan

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Abstract

The present study, conducted between 2022 and 2023, aimed to document the floristic diversity, life forms, and leaf spectra of the vegetation from Gilgit to Raikot in the Gilgit District. Phytosociological analysis was performed to identify the dominant species, life forms, and leaf size spectra, with the area divided into four stands and thirty quadrats sampled per stand to calculate the Importance Value Index (IVI). A total of 181 phanerogamic species were recorded from 138 genera and 61 families, establishing a comprehensive inventory of the flora. In terms of habit categories, herbs dominated with 134 species (74%), while hemicryptophytes led life forms with 74 species (40.9%). Microphylls (44.2%) and nanophylls (23.8%) were the most common leaf sizes. Hemicryptophytic herbs with microphyllous and nanophyllous leaves exhibit vital adaptations to cold climates, reducing water loss, resisting winds, and leveraging snow insulation. *Polygonum maritimum*, a dominant prostrate perennial with an IVI of 47.2, stabilizes soil, supports nutrient cycling, and indicates cold climatic conditions while contributing significantly to ecosystem resilience and biodiversity. One-way ANOVA ($P < 0.0001$) revealed significant differences between Stand 3 and Stand 4, with Stand 4, a rocky, barren area, exhibiting lower diversity due to variations in altitude, soil, and vegetation. This study provides essential baseline data on plant diversity and ecological structure in the Gilgit to Raikot region and the importance of the need for targeted conservation. Future research should monitor long-term environmental changes and the effects of anthropogenic activities on biodiversity.

Key Words: Floral Diversity; Biological Spectra; Leaf spectra; Physiognomic; Ecosystem

Introduction

Natural ecosystems are subject to disturbances that vary in duration, frequency, and intensity, significantly shaping vegetation structure. Chronic disorders, while typically low in intensity, can cause substantial damage due to their high frequency and prolonged duration, as highlighted by Macêdo *et al.* (2024). These disturbances often stem from anthropogenic activities, particularly land use for agriculture and the direct exploitation of natural resources (Young *et al.* 2016; Antongiovanni *et al.* 2020). Understanding human impacts on ecosystems is key to conservation (Khadim *et al.* 2024). Floristic diversity, or the variety of plant species, is influenced by climate, soil, and human activities (Kent and Coker 1992). By analyzing plant species diversity and distribution through floristic composition, we can increase our understanding of how these various factors interact and contribute to ecological dynamics (Karima *et al.* 2024). Key indicators of floral biodiversity, such as species abundance

and environmental variation, are influenced by a diversity of biotic and abiotic factors (Gul *et al.* 2018). This connection between species diversity and environmental factors is essential for evaluating ecosystem health and stability in light of ongoing anthropogenic pressures. Investigating the floristic composition of specific environments highlights the broader biological influences on plant diversity and distribution (Gul *et al.* 2018; Hussain *et al.* 2020; Karima *et al.* 2024). Such insights are instrumental in understanding the complex interplay between various ecological and human-induced factors, enabling more informed decision-making regarding conservation efforts. This analysis highlights weather patterns' role in ecological dynamics, guiding conservation strategies and supporting ecosystem resilience amid environmental changes (Manan *et al.* 2022; Zehra *et al.* 2024).

Plant life forms are key indicators of an area's climatic and environmental conditions, shaped by factors such as grazing and human activities (Jahangeer *et al.* 2020).

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These pressures, along with seasonal changes, often lead to an increase in therophytes and chamaephytes. By representing growth forms, plant life forms reveal important relationships with environmental components, highlighting ecological shifts and plant adaptations (Cain and Castro 1959). Studying these life forms offers valuable insights into plant community structure and plant-environment interactions, independent of taxonomic classifications. In ecological research, analyzing plant life forms helps to understand climatic conditions, plant adaptations, and the geographical distribution of plant communities, reflecting overall vegetation structure (Raunkiaer 1934). Raunkiaer classified plants based on the position of their penetrating buds: Phanerophytes (Ph) have buds 25 cm or more above ground, including woody trees and shrubs; Chamaephytes (Ch) have buds up to 25 cm above ground, mostly small shrubs; Hemicytrophytes (He) have buds at ground level, protected by soil and leaves, including grasses; Geophytes (Ge) have buds below ground or submerged, characterized by tubers, rhizomes, or bulbs; and Therophytes (Th) are annual plants completing their life cycle during favorable seasons, typically found in desert grasslands and cultivated fields (Haider and Ibrahim 2022).

Leaf size spectra are essential for understanding plant eco-physiological processes. Variations in leaf size, influenced by elevation, reflect the unique climate and soil conditions at different altitudes. These changes in leaf size help characterize the area's environmental traits (Badshah *et al.* 2013). Furthermore, leaf physiognomy plays a critical role in defining plant types and contributes to paleo-environmental research. Additionally, leaf size is correlated with climatic characteristics and geographic position (Batalha and Martins 2002), providing valuable insights into local climatic conditions (Sintayehu 2018). Together, these factors highlight the importance of leaf size in understanding the complex relationships between plants and their environments. Leaf size classes are valuable for classifying plant associations, with spectra determined by categorizing mature leaves as described by Raunkiaer (1934). The classifications are as follows: Leptophyll (L) has a leaf size of 25 mm²; Naznophyll (N) is 225 mm²; Microphyll (Mi) measures 2,025 mm²; Mesophyll (Me) is 18,225 mm²; Megaphyll (Ma) ranges from 164,025 mm²; and Macrophyll (Ma) refers to leaf sizes greater than 164,025 mm².

The increasing construction and development activities surrounding the KKH have led to a significant gap in comprehensive studies on the area's plant diversity and biological spectrum. Previous research has insufficiently addressed the impacts of these developments on local flora, hindering effective conservation strategies. This research aims to conduct a thorough investigation of plant diversity in the unexplored regions surrounding the KKH, specifically assessing overall plant diversity, analyzing the biological spectrum, evaluating the impacts of ongoing development, and providing baseline data to inform conservation efforts and sustainable management practices.

Materials and Methods

Investigation site

Gilgit is located at 35°55'2.61"N and 74°18'38.60"E, while Raikot is at 35°29'30.10"N and 74°35'30.81"E. The elevation in the area ranges from 1,150 m to 4500 m, with an average annual temperature of 24°C, northwesterly winds at 5 km/h, and 55% humidity. Situated on the left bank of the Indus River and surrounded by rugged hills, the area shows significant ecological heterogeneity shaped by soil, climate, altitude, and varied slopes. Cooler, moister northern slopes support specialized species, while drier, sunlit southern slopes favor drought-tolerant plants, influencing species composition and diversity. The region experiences mild summers, especially in June and July (Manan *et al.* 2020). Biological variability is influenced by elevation and human activities (Haider and Ibrahim 2022). The map of the study area is shown in (Fig. 1).

Field survey

The tools used for the field survey included a field notebook, pencil, cutter, gloves, measuring tape, string, plastic bags, mobile camera, plant press, and dryer. During the survey, plant specimens were carefully collected, pressed, and dried using the plant press and dryer (Abbas *et al.* 2019; Khadim *et al.* 2024).

Plant collection, preservation and identification

Multiple field surveys were conducted in the study area using standard ecological methods to gather comprehensive qualitative and quantitative data, including plant specimens, field observations, and altitude measurements obtained via GPS to delineate ecological zones. Plant specimens were pressed, dried, and mounted on standardized herbarium sheets (11.5 × 17.5 inches) for identification (Shahab Ud Din *et al.* 2024) using the Flora of Pakistan (Ali and Qaiser 1986). Prescribed taxonomic protocols were followed for data collection and processing, with conventional methods employed for plant species identification (Abbas *et al.* 2024; Karima *et al.* 2024). Although plant identification faced challenges due to incomplete specimens and limited resources, issues of taxonomic endemism and complexity were minimized by ongoing research efforts in northern Pakistan. Finally, the collected plant species were submitted to the Herbarium Department of Plant Sciences at Karakoram International University Gilgit, Pakistan.

Phytosociological studies

Phytosociological studies were conducted using the plant plot sampling method (Quadrat Method). The study area is divided into four stands based on altitude and distance.

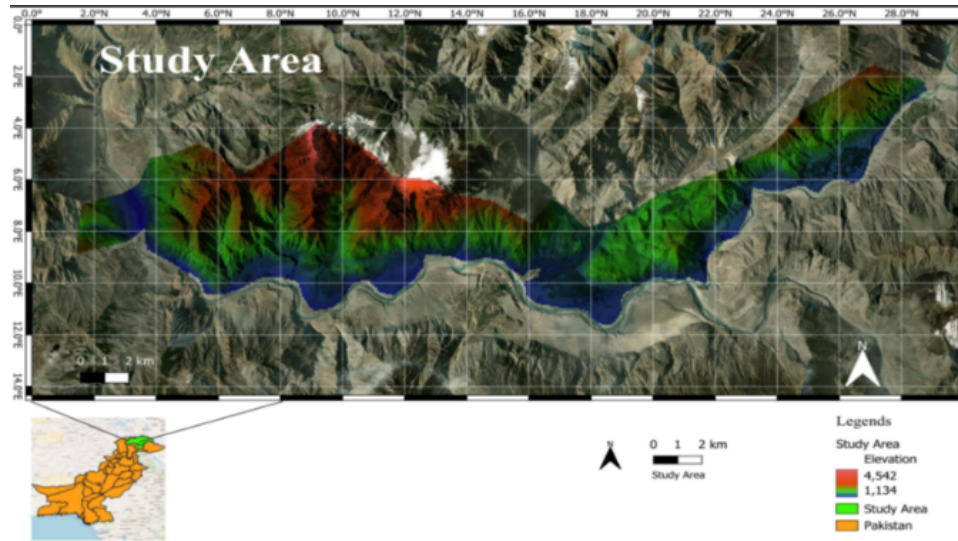


Fig. 1: Map of the study area

Each stand had 30 randomly selected quadrats: 10 for tree sampling and 20 for herbs and shrubs. This approach met the minimum ecological sampling criteria, covering at least 5% of the sample area. Quadrat size selection was based on prior research and flora distribution patterns. Sparse herbaceous and shrub vegetation used 5×5 m quadrats, while sparse tree vegetation used 10×10 m, effectively assessing the area's multi-story vegetation (Karima *et al.* 2024; Zehra *et al.* 2024). Quantitative data were recorded in the phytosociological field notebook, and leaf size spectra were calculated and noted in the field observation notebook.

Data analysis

The following formulas were used to calculate different phytosociological attributes (Arif and Haider 2022).

$$\text{Frequency} = \frac{\text{Number of quadrats which occur}}{\text{Total quadrates}}$$

$$\text{Relative frequency} = \frac{\text{Absolute frequency of a species}}{\text{Sum of absolute frequency of all species}} \times 100$$

$$\text{Density} = \frac{\text{Total number of all individuals of a species in all quadrates}}{\text{Total No. of quadrates}}$$

$$\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Total individuals of all species}} \times 100$$

$$\text{Cover} = \frac{\text{Total cover of a species occurred in all quadrates}}{\text{Total number of individual of a species occurred in all quadrates}}$$

$$\text{Relative cover} = \frac{\text{Total cover of all individuals of a species}}{\text{Total cover of all species occurred in all quadrates}} \times 100$$

$$\text{Importance Value Index} = \text{Relative frequency} + \text{Relative density} + \text{Relative cover}$$

We used the Importance Value Index (IVI), introduced by Curtis and McIntosh (1951), as a widely used metric in vegetation ecology to assess the relative ecological significance of species within a community by integrating their

relative frequency, relative density, and relative dominance. It provides a holistic view of a species' role in ecosystem structure and function. However, IVI is not without limitations. While it effectively highlights dominant species, it may oversimplify ecological complexity, overlooking critical species interactions, environmental gradients, and the contribution of rare or less abundant species.

K-means clustering algorithm

Using Origin2024b, K-Means clustering based on the Importance Value Index (IVI) revealed distinct ecological patterns, grouping data points with similar characteristics (Vaish *et al.* 2021; Ali *et al.* 2022). The optimal number of clusters was determined using the Elbow Method, where the Within-Cluster Sum of Squares (WCSS) was plotted against the number of clusters (k). A clear "elbow" point indicated an optimal balance between model simplicity and explanatory power (Jiménez-Preciado *et al.* 2024).

We used One-Way ANOVA to identify significant differences in species distribution among groups, as it is suitable for comparing means across multiple groups, providing a statistical basis for understanding ecological variations. We also employed Principal Component Analysis (PCA) to capture the maximum variance in the dataset, identifying key ecological gradients and supporting the observed distributional patterns (Hassan *et al.* 2024).

Results

Taxonomic and physiognomic characteristics of the study area

The study area is rich in floral diversity, comprising 181 species distributed across 138 genera and 61 families depicted in Table 1.

Table 1: Inventory, taxonomic attributes, physiognomic traits, and elevation range of the recorded flora

S. No	Family	Species Name	Voucher Number	Habit	Life forms	Leaf spectrum	Elevation
1	Alliaceae	<i>Allium cepa</i> Linn	GR-124	Herb	Geo	Nano	1187
2	Alliaceae	<i>Allium carolinianum</i> DC.	GR-125	Herb	Hem	Mic	1166
3	Amranthaceae	<i>Amranthus retroflexus</i> L.	GR-126	Herb	Th	Mic	1279
4	Amranthaceae	<i>Amranthus viridis</i> L.	GR-127	Herb	Th	Mic	1347
5	Amranthaceae	<i>Kochia prostrata</i> (L.) Schard	GR-128	Herb	Th	Nano	1374
6	Amranthaceae	<i>Kochia scorparia</i> (L) Schard	GR-129	Herb	Th	Mic	1355
7	Apiaceae	<i>Corriandrum sativum</i> L.	GR-130	Herb	Th	Lep	1186
8	Apiaceae	<i>Daucus carota</i> L.	GR-131	Herb	Th	Nano	1174
9	Apiaceae	<i>Foeniculum vulgare</i> Mill	GR-132	Herb	Th	Nano	1243
10	Apiaceae	<i>Heracleum sphondylium</i> L.	GR-133	Herb	Hem	Mic	1327
11	Apocynaceae	<i>Nerium oleander</i> L.	GR-134	Shurb	Ph	Mic	1361
12	Apocynaceae	<i>Vinca minor</i> L.	GR-135	Shurb	Ch	Mic	1241
13	Ascelpidaceae	<i>Vincetoxicum canescense</i> (Wild) Decne	GR-136	Herb	Hem	Mic	1182
14	Ascelpidaceae	<i>Acelpias vincetoxicum</i> Linn	GR-137	Herb	Th	Mic	1181
15	Asteraceae	<i>Anaphalis virgata</i> Thomson. ex, C.B Carke	GR-138	Herb	Hem	Nano	1265
16	Asteraceae	<i>Artemisia capillaris</i> Miq	GR-139	Herb	Hem	Mic	1379
17	Asteraceae	<i>Artemisia annua</i> L.	GR-140	Herb	Th	Lep	1165
18	Asteraceae	<i>Artemisia brevifolia</i> wall. Ex DC.	GR-141	Herb	Ch	Mic	1365
19	Asteraceae	<i>Artemisia dranunculus</i> L.	GR-142	Herb	Ch	Mic	1385
20	Asteraceae	<i>Artemisia gmelinii</i> Webber .ex Stechn	GR-143	Herb	Ch	Lep	1271
21	Asteraceae	<i>Artemisia rutifolia</i> Stephan ex Spreng	GR-144	Sub-Shrub	Ch	Nano	1346
22	Asteraceae	<i>Artemisia scorparia</i> Waldst and Kit	GR-145	Herb	Hem	Lep	1166
23	Asteraceae	<i>Artemisia siversiana</i> Ehrh.ex Willd	GR-146	Herb	Th	Lep	1357
24	Asteraceae	<i>Artemisia vulgaris</i> L.	GR-147	Herb	Ch	Mic	1272
25	Asteraceae	<i>Carthamus tinctorius</i> L.	GR-148	Herb	Hem	Mic	1188
26	Asteraceae	<i>Chrysanthemum indicum</i> L.	GR-149	Herb	Ch	Mic	1162
27	Asteraceae	<i>Cichorium intybus</i> L.	GR-150	Herb	Hem	Mes	1179
28	Asteraceae	<i>Conyza bonariensis</i> L.	GR-151	Herb	Th	Nano	1267
29	Asteraceae	<i>Crepis flexuosa</i> (Lebeb) (Benth)	GR-152	Herb	Hem	Nano	1176
30	Solanaceae	<i>Datura stramonium</i> Var .tatula (L.) Torr	GR-153	Herb	Th	Mes	1330
31	Asteraceae	<i>Echinops cornigerus</i> DC.	GR-154	Herb	Th	Mic	1166
32	Asteraceae	<i>Erigerion canadensis</i> (L.)	GR-155	Herb	Th	Nano	1264
33	Asteraceae	<i>Galinsoga parvifolia</i> Cav.	GR-156	Herb	Th	Lep	1184
34	Asteraceae	<i>Helianthus annus</i> L.	GR-157	Shurb	Th	Mac	1151
35	Asteraceae	<i>Hieracium umbellatum</i> L.	GR-158	Herb	Hem	Mic	1177
36	Asteraceae	<i>Jurinea himalica</i> R.R.Stewart	GR-159	Herb	Hem	Mes	1169
37	Asteraceae	<i>Lactuca sativa</i> L.	GR-160	Herb	Th	Mac	1189
38	Asteraceae	<i>Scorzonera virgata</i> DC.	GR-161	Herb	Hem	Mic	1372
39	Asteraceae	<i>Sonchus asper</i> (L) Hill	GR-162	Herb	Hem	Mic	1261
40	Asteraceae	<i>Soncio tibeticus</i> Hook.f.	GR-163	Herb	Hem	Mes	1265
41	Asteraceae	<i>Tagetes erecta</i> L.	GR-164	Herb	Th	Nano	1388
42	Asteraceae	<i>Tancetum artemisiodes</i> Sch.Bip.ex Hoof .f	GR-165	Herb	Hem	Lep	1277
43	Asteraceae	<i>Taraxacum officinalis</i> F.H.Wiggers	GR-166	Herb	Hem	Lep	1180
44	Asteraceae	<i>Taraxcum latibase</i> Soest.	GR-167	Herb	Hem	Nano	1159
45	Berbidaceae	<i>Berberris orthobotys</i> Bein .ex Aitch	GR-168	Shurb	Ph	Nano	1279
46	Blassminaceae	<i>Impatiens brachycentra</i> Kar and Kir	GR-169	Herb	Th	Mic	1501
47	Borginaceae	<i>Cynoglossum goldchium</i> Wall.ex Benth	GR-170	Herb	Hem	Mes	1361
48	Borginaceae	<i>Heliotropium dasycarpum</i> Ledeb.	GR-171	Herb	Ch	Mes	1284
49	Borginaceae	<i>Lendilofia stylosa</i> (Kar and Kir).	GR-172	Herb	Hem	Mic	1371
50	Borginaceae	<i>Mysotis alpestris</i> F.w Schmid.	GR-173	Herb	Hem	Mic	1378
51	Brassicaceae	<i>Barbarea vulgaris</i> W.T Alton	GR-174	Herb	Hem	Nano	1188
52	Brassicaceae	<i>Brassica campestris</i> Linn	GR-175	Herb	Th	Mic	1160
53	Brassicaceae	<i>Brassica juncea</i> (L.) Czern	GR-176	Herb	Th	Mic	1351
54	Brassicaceae	<i>Brassica oleraceae</i> L.	GR-177	Herb	Hem	Mic	1189
55	Brassicaceae	<i>Descuriana Sophia</i> (L.) Webbex. Prantal	GR-178	Herb	Hem	Nano	1381
56	Brassicaceae	<i>Mettihoila flavida</i> Boiss	GR-179	Herb	Hem	Mes	1165
57	Brassicaceae	<i>Raphanus sativus</i> L.	GR-180	Herb	Th	Mic	1189
58	Brassicaceae	<i>Cannabis sativa</i> L.	GR-181	Herb	Th	Mic	1165
59	Canabaceae	<i>Capsella bursa pastoris</i> (L.) Medik	GR-182	Herb	Hem	Mes	1362
60	Canabaceae	<i>Celtis caucasica</i> Willd.	GR-183	Herb	Hem	Mic	1285
61	Cappridaceae	<i>Cappiris spinosa</i> Linn	GR-184	Shurb	Ch	Mic	1348
62	Caryophyllaceae	<i>Cerastium glomeratum</i> Thuill.	GR-185	Herb	Th	Mes	1361
63	Caryophyllaceae	<i>Cerastium caespitosum</i> Gilib.	GR-186	Herb	Hem	Nano	1325
64	Caryophyllaceae	<i>Dianthus orientalis</i> (Adams)	GR-187	Herb	Hem	Nano	1272
65	Caryophyllaceae	<i>Silene kunawariensis</i> Benth	GR-188	Herb	Hem	Mic	1254

Table 1: Continued

Table 1: Continued

66	Caryophyllaceae	<i>Silene vulgaris</i> (Monech) Garcke	GR-189	Herb	Hem	Nano	1273
67	Celastraceae	<i>Euonymus japonicus</i> Thunb	GR-190	Shurb	Ch	Mic	1275
68	Chenopodiaceae	<i>Chenopodium album</i> L.	GR-191	Herb	Th	Mic	1254
69	Chenopodiaceae	<i>Chenopodium botrys</i> (L.) Mosyakin and Celmants	GR-192	Herb	Hem	Mic	1369
70	Chenopodiaceae	<i>Krascheninnikovia ceratoides</i> (L) Gulden.	GR-193	Shurb	Ch	Mic	1500
71	Chenopodiaceae	<i>Salsola tragus</i> L.	GR-194	Shurb	Ch	Nano	1158
72	Chenopodiaceae	<i>Suaeda heterophylla</i> (Kar and Kir)	GR-195	Herb	Th	Nano	1172
73	Convolvulaceae	<i>Cuscuta europaea</i> L.	GR-196	Herb	Th	Mic	1261
74	Cucurbitaceae	<i>Cucumis melo</i> Var.Cultus Kurz	GR-197	Herb	Th	Mac	1384
75	Cupressaceae	<i>Juniperus excelsa</i> M.Bieb.	GR-198	Tree	Ph	Lep	1354
76	Cyperaceae	<i>Cyperus articulatus</i> L.	GR-199	Herb	Hem	Mic	1233
77	Cyperaceae	<i>Cyperus rotundus</i> L.	GR-200	Herb	Hem	Mic	1322
78	Ebenaceae	<i>Diospyros kaki</i> Linn.	GR-201	Tree	Ph	Meg	1353
79	Eleagnaceae	<i>Elegans angustifolia</i> L.	GR-202	Tree	Ph	Mes	1350
80	Eleagnaceae	<i>Elegans umbellata</i> Thunb.	GR-203	Tree	Ph	Mic	1187
81	Eleagnaceae	<i>Hippophae rhamnoides</i> L.	GR-204	Shurb	Ph	Nano	1500
82	Ephedraceae	<i>Ephedra intermedia</i> Schroenk and C.A .Mey.	GR-205	Shurb	Ph	Mac	1188
83	Equisetaceae.	<i>Equisetum arvense</i> L.	GR-206	Herb	Geo	Lep	1187
84	Euphorbiaceae	<i>Acalypha wilkesiana</i> Müll. Arg.Ph	GR-207	Shurb	Th	Nano	1187
85	Fabaaceae	<i>Trifolium pratense</i> L.	GR-208	Herb	Hem	Nano	1288
86	Fabaceae	<i>Cicer microphyllum</i> Benth	GR-209	Herb	Hem	Nano	1279
87	Fabaceae	<i>Medicago sativa</i> L.	GR-210	Herb	Hem	Nano	1230
88	Fabaceae	<i>Phaseolus vulgaris</i> L.	GR-211	Herb	Th	Mic	1164
89	Fabaceae	<i>Rubinia pseudoacacia</i>	GR-212	Tree	Ph	Nano	1380
90	Fabaceae	<i>Sophora mollis</i> (Royle)	GR-213	Shurb	Hem	Nano	1170
91	Fabaceae	<i>Trifolium repens</i> L.	GR-214	Herb	Geo	Nano	1170
92	Fabaceae	<i>Vicia faba</i> L.	GR-215	Herb	Th	Mic	1259
93	Fumiraceae	<i>Cordylis adiantifolia</i> (Hook.f.and Thomson)	GR-216	Herb	Hem	Mic	1235
94	Fumiraceae	<i>Fumirica indica</i> (Hauskn)	GR-217	Herb	Th	Nano	1259
95	Gentniaceae	<i>Swertia cordata</i> (wall.ex.G.Don)	GR-218	Herb	Th	Nano	1171
96	Gerniaceae	<i>Geranium pratense</i> L.	GR-219	Herb	Hem	Mic	1152
97	Grossulariaceae	<i>Ribes alpestre</i> Wall.ex Decne	GR-220	Shurb	Ph	Mic	1257
98	Grossulariaceae	<i>Ribes orientale</i> Def. His Arb	GR-221	Shurb	Ph	Mic	1277
99	Iridiaceae	<i>Iridis pseudocorus</i> L.	GR-222	Herb	Hem	Mac	1186
100	Juglandaceae	<i>Juglanas regia</i> L.	GR-223	Tree	Ph	Mes	1185
101	Lamiaceae	<i>Isodon rousus</i> Wall.ex Benth	GR-224	Herb	Th	Mes	1231
102	Lamiaceae	<i>Mentha arvensis</i> L.	GR-225	Herb	Geo	Mic	1266
103	Lamiaceae	<i>Mentha longifolia</i> (L.) Huds	GR-226	Herb	Geo	Nano	1181
104	Lamiaceae	<i>Nepeta cataria</i> L.	GR-227	Herb	Hem	Mic	1181
105	Lamiaceae	<i>Nepeta discolor</i> Royle ex Benth	GR-228	Herb	Hem	Nano	1172
106	Malvaceae	<i>Malva verticillata</i> L.	GR-229	Herb	Th	Mic	1273
107	Moraceae	<i>Ficus carica</i> L.	GR-230	Tree	Ph	Mes	1169
108	Moraceae	<i>Morus alba</i> Var.Serrata (Roxb)	GR-231	Tree	Ph	Mes	1265
109	Myrtaceae	<i>Callistemon viminalis</i> (Sol.ex Gaetn) G.Don	GR-232	Shurb	Ch	Mic	1265
110	Oleaceae	<i>Olea europea</i> L.	GR-233	Shurb	Ch	Mic	1161
111	Onagraceae	<i>Epilobium hirsutum</i> L.	GR-234	Herb	Hem	Nano	1274
112	Onagraceae	<i>Epilobium palustre</i> (L.) Schard.	GR-235	Herb	Hem	Mic	1177
113	Onagraceae	<i>Pistacia khinjuk</i> Stocks	GR-236	Tree	Ph	Mic	1184
114	Orchidaceae	<i>Dactylorhiza hatergria</i> L.	GR-237	Herb	Th	Nano	1189
115	Oxilidaceae	<i>Oxalis coriculata</i> L.	GR-238	Herb	Geo	Mic	1159
116	Papavaceae	<i>Papaver somniferum</i> L.	GR-239	Herb	Th	Mic	1159
117	Poaceae	<i>Phragmites karka</i> (Retz.) Trin. ex Steud.	GR-240	Herb	Hem	Mic	1269
118	Plantaginaceae	<i>Plantago himalaica</i> Pilg.	GR-241	Herb	Hem	Mic	1165
119	Plantaginaceae	<i>Plantago lanceolata</i> L.	GR-242	Herb	Hem	Mes	1245
120	Plantaginaceae	<i>Plantago major</i> L.	GR-243	Herb	Hem	Mic	1129
121	Platanaceae	<i>Platanus orientalis</i> L.	GR-244	Tree	Ph	Meg	1323
122	Poaceae	<i>Cynodon dactylon</i> (L.)	GR-245	Herb	Hem	Lep	1233
123	Poaceae	<i>Dactylis glomeratum</i> L.	GR-246	Herb	Th	Nano	1165
124	Poaceae	<i>Eriochloa fatmensis</i> (Hochst.and Steud)	GR-247	Herb	Th	Mic	1162
125	Poaceae	<i>panicum antidotale</i> Retz.	GR-248	Herb	Hem	Mic	1244
126	Poaceae	<i>Poa annua</i> L.	GR-249	Herb	Th	Lep	1143
127	Poaceae	<i>Saccharum filifolium</i> Steud	GR-250	Herb	Hem	Mes	1185
128	Poaceae	<i>Savia pumilla</i> (Poir) Roem. And Schul)	GR-251	Herb	Th	Lep	1200
129	Poaceae	<i>Sorghum halpense</i> (L.)	GR-252	Herb	Hem	Mic	1166
130	Polygonaceae	<i>Fagopyrum esculentum</i> Moench	GR-253	Herb	Hem	Mic	1289
131	Polygonaceae	<i>Polygonum aviculare</i> L.	GR-254	Herb	Hem	Lep	1185
132	Polygonaceae	<i>Polygonum effusum</i> Mesin	GR-255	Herb	Th	Mic	1192

Table 1: Continued

Table 1: Continued

133	Polygonaceae	<i>Polygonum maritimum</i> L.	GR-256	Herb	Hem	Mic	1277
134	Polygonaceae	<i>Polygonum parnchyoides</i> C.A.Mey	GR-257	Herb	Hem	Nano	1174
135	Polygonaceae	<i>Rumax dentatus</i> L.	GR-258	Herb	Ch	Mes	1283
136	Polygonaceae	<i>Rumax hastatus</i> D.Don	GR-259	Herb	Ch	Mes	1187
137	Polygonaceae	<i>Rumax nepalensis</i> Sprengel	GR-260	Herb	Hem	Mes	1269
138	Polygonaceae	<i>Rumax patientia</i> L.	GR-261	Herb	Hem	Mac	1252
139	Portulacaceae	<i>Portulaca oleraceae</i> L.	GR-262	Herb	Hem	Nano	1281
140	Pteridiaceae	<i>Adiantum aleuticum</i> (Rupr.) C.A. Paris	GR-263	Herb	Hem	Nano	1274
141	Pteridiaceae	<i>Adiantum capillus vineris</i> L.	GR-264	Herb	Geo	Lep	1233
142	Pteridiaceae	<i>Adiantum pedatum</i> L.	GR-265	Herb	Geo	Mes	1330
143	Pteridiaceae	<i>Chelanthus tomentosa</i> (Link). Fee	GR-266	Herb	Hem	Mic	1356
144	Puniaceae	<i>Punica granatum</i> L.	GR-267	Tree	Ph	Mic	1288
145	Ranunculaceae	<i>Clematis orientalis</i> L.	GR-268	Herb	Hem	Mic	1190
146	Ranunculaceae	<i>Ranunculus arvensis</i> L.	GR-269	Herb	Hem	Mic	1265
147	Ranunculaceae	<i>Ranunculus pulchellus</i> C.A .Mey	GR-270	Herb	Hem	Mic	1270
148	Ranunculaceae	<i>Ranunculus repens</i> (L.)	GR-271	Herb	Th	Mic	1233
149	Rosaceae	<i>Cydonia oblonga</i> (Mill)	GR-272	Tree	Ph	Mac	1181
150	Rosaceae	<i>Eriobuturya japonica</i> Lindl	GR-273	Tree	Ph	Mes	1252
151	Rosaceae	<i>Fagaria nubicola</i> Lindl .ex Laciata	GR-274	Herb	Hem	Nano	1188
152	Rosaceae	<i>Malus pumilla</i> Mill	GR-275	Tree	Ph	Mes	1352
153	Rosaceae	<i>Prunus amygdalus</i> Batsch	GR-276	Tree	Ph	Mic	1164
154	Rosaceae	<i>Prunus armenica</i> L.	GR-277	Tree	Ph	Mes	1286
155	Rosaceae	<i>Prunus avium</i> (L.)	GR-278	Tree	Ph	Mes	1165
156	Rosaceae	<i>Prunus persica</i> (L.) Batsch	GR-279	Tree	Ph	Mes	1155
157	Rosaceae	<i>Rosa webbiana</i> Wall.ex Royle.	GR-280	Shurb	Ph	Nano	1168
158	Rubiaceae	<i>Gallium verum</i> L.	GR-281	Herb	Hem	Mic	1161
159	Rubiaceae	<i>Rubia cordifolia</i> Linn	GR-282	Herb	Hem	Mic	1268
160	Rutaceae	<i>Citrus sinensis</i> (L.) O Sbeck	GR-283	Tree	Ph	Mes	1377
161	Rutaceae	<i>Haplophylum gelesii</i> (Hemsl) C.C,Towns	GR-284	Herb	Hem	Mic	1222
162	Salicaceae	<i>Populus alba</i> L.	GR-285	Tree	Ph	Mes	1367
163	Salicaceae	<i>Populus nigra</i> L.	GR-286	Tree	Ph	Mes	1385
164	Salicaceae	<i>Salix alba</i> L.	GR-287	Tree	Ph	Nano	1249
165	Scrophylariaceae	<i>Verbascum thapsus</i> L.	GR-288	Herb	Hem	Mic	1367
166	Simbouraceae	<i>Alianthus altissima</i> (Mill) Swingle	GR-289	Tree	Ph	Mes	1260
167	Solanaceae	<i>Capsicum annum</i> L.	GR-290	Herb	Th	Mic	1254
168	Solanaceae	<i>Solanum lycopersicum</i> L.	GR-291	Herb	Th	Mic	1230
169	Solanaceae	<i>Solanum melongena</i> L.	GR-292	Herb	Hem	Mes	1160
170	Solanaceae	<i>Solanum nigrum</i> L.	GR-293	Herb	Th	Mes	1160
171	Solanaceae	<i>Solanum surrattense</i> L.	GR-294	Herb	Hem	Mes	1169
172	Tamariaceae	<i>Myricarea squamosa</i> Desv.	GR-295	Shurb	Ph	Mic	1248
173	Tamiraceae	<i>Tamarix arceuthoides</i> Burge	GR-296	Shurb	Ph	Lep	1385
174	Tamiraceae	<i>Tamarix indica</i> Willd	GR-297	Tree	Ph	Nano	1247
175	Thymelaceae	<i>Dephane mucronata</i> Royle	GR-298	Shurb	Ch	Nano	1279
176	Ulmaceae	<i>Ulmus laciniata</i> (Trautv) Mayr	GR-299	Tree	Ph	Mic	1244
177	Urtiaceae	<i>Urtica dioca</i> L.	GR-300	Herb	Hem	Mic	1361
178	Vitaceae	<i>Vitis vinifera</i> L.	GR-301	Herb	Ph	Mac	1375
179	Zygophyllaceae	<i>Peganum harmala</i> L.	GR-302	Herb	Hem	Mic	1359
180	Zygophyllaceae	<i>Fagonia indica</i> Burm. f.	GR-303	Tree	Ph	Mic	1250
181	Zygophyllaceae	<i>Tribulus terrestris</i> L.	GR-304	Herb	Hem	Nano	1129

Note: GR Gilgit Raikot

In terms of habit, herbs dominate with 134 species (74%), while trees and shrubs account for 26 species (14.4%) and 20 species (11%), respectively, and sub-shrubs make up 1 species (0.55%). Regarding life forms, hemicryptophytes represent the largest group with 74 species (40.9%), followed by therophytes with 46 species (25.4%) and phanerophytes with 36 species (19.9%). The leaf size spectra analysis reveals a predominance of microphylls (44.2%) and nanophylls (23.8%), reflecting adaptations to the region's cold and harsh environmental conditions Fig. 2. Additionally, Asteraceae emerged as the dominant family with 30 species, followed by Rosaceae and Polygonaceae, each represented by 9 species. The other families had fewer than 9 species, as illustrated in Fig. 3.

Stand-1: The assessment of plant diversity in Stand 1 identified 40 distinct plant species across 34 genera and 19 families. The dominant habit categories included herbs, which comprised 34 species (85.0%), followed by trees (4 species, 10.0%) and shrubs (2 species, 5.0%). Among life forms, hemicryptophytes were the most prevalent (18 species, 45.0%), followed by therophytes (14 species, 35.0%), phanerophytes (4 species, 10.0%), chamaephytes (3 species, 7.5%), and geophytes (1 species, 2.5%). The leaf size spectra analysis showed that microphylls were the most common (16 species, 40.0%), followed by nanophylls (10 species, 25.0%), leptophylls (3 species, 7.5%), mesophylls (10 species, 25.0%), and macrophylls (1 species, 2.5%) Fig. 4.

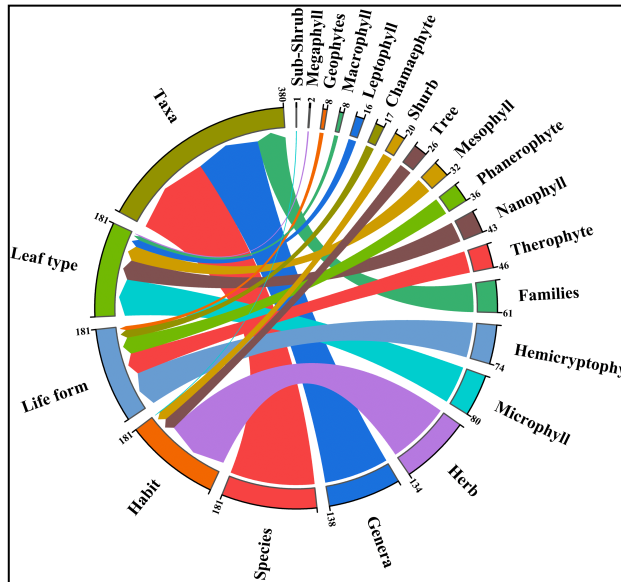


Fig. 2: Floristic composition of the study area

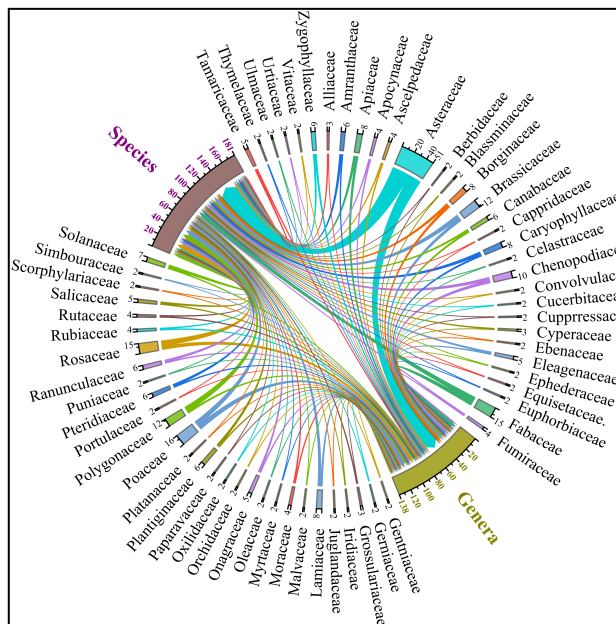


Fig. 3: Recorded families with number of species and genera in the study area

Stand -2: In stand-2 the results revealed 46 species across 41 genera and 18 families. In terms of habit, herbs were the dominant group with 36 species (78.26%), followed by trees with 8 species (17.39%) and shrubs with 2 species (4.35%). Among life forms, hemicryptophytes were the most prevalent, accounting for 16 species (34.78%), followed by therophytes with 15 species (32.61%), phanerophytes with 10 species (21.74%), chamaephytes with 4 species (8.70%), and geophytes with 1 species (2.17%). Leaf size analysis revealed that microphylls were the most common with 15 species (32.61%), followed by mesophylls with 13 species

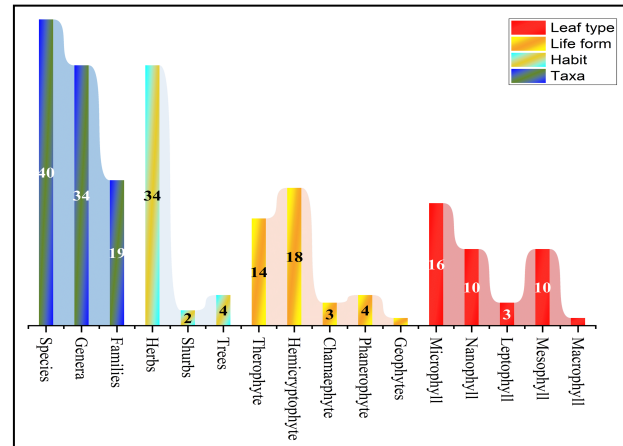


Fig. 4: Taxonomic and physiognomic characteristics of stand-1 in the study area

(28.26%), nanophylls with 12 species (26.09%), leptophylls with 4 species (8.70%), and macrophylls with 2 species (4.35%) Fig. 5.

Stand -3: The data represents 30 species across 25 genera and 17 families, 23 species (76.67%) being herbaceous plants and 7 (23.33%) shrubs species. In terms of life forms, 18 species (60%) are hemicryptophytes, followed by 4 species (13.33%) each of therophytes and chamaephytes, 3 species (10%) of phanerophytes, and 1 species (3.33%) of geophytes. Regarding leaf size, 15 species (50%) have microphyll leaves, 8 species (26.67%) mesophyll, 4 species (13.33%) nanophyll, 2 species (6.67%) leptophyll, and 1 species (3.33%) macrophyll. The dominance of hemicryptophytes and microphyllous species indicates that most plants are adapted to harsh, possibly arid environments, prioritizing water conservation and resilience Fig. 6.

Stand -4: The data shows a total of 23 species across 22 genera and 12 families. The majority are herbs, with 19 species (82.61%), followed by trees with 3 species (13.04%), and shrubs with 1 species (4.35%). Regarding life forms, hemicryptophytes dominate with 11 species (47.83%), followed by therophytes and chamaephytes, each with 4 species (17.39%), phanerophytes with 3 species (13.04%), and geophytes with 1 species (4.35%). For leaf types, microphyll leaves are the most common, found in 10 species (43.48%), followed by mesophyll leaves in 8 species (34.78%), nanophyll in 4 species (17.39%), and leptophyll in 1 species (4.35%) Fig. 7.

Dominant species based on IVI value across all stands

The dominant taxa based on IVI values are revealed across four stands. In Stand-1, *Poa annua* (IVI = 27.065) is the most significant, while *Amaranthus viridis* (IVI = 24.065) and *Medicago sativa* (IVI = 25.94) dominate Stand-2. *Cannabis sativa* leads Stand 3 with an IVI of 29.92. Stand-4 is dominated by *Polygonum maritimum* (IVI = 47.228), followed by *Capparis spinosa* and *Solanum surrattense*

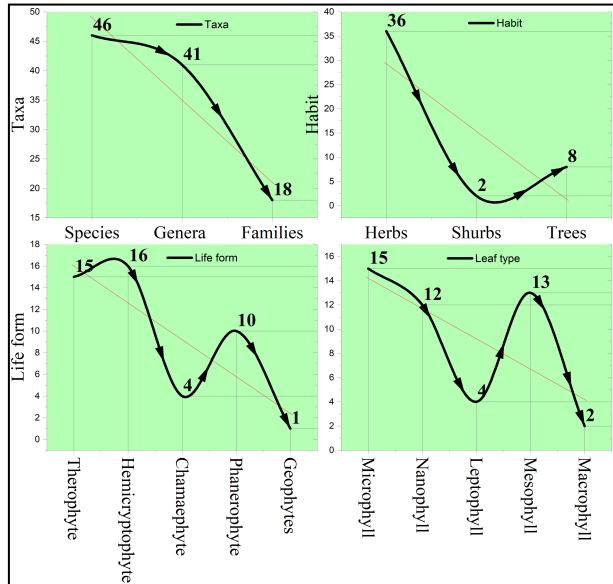


Fig. 5: Taxonomic and physiognomic characteristics of stand-2 in the study area

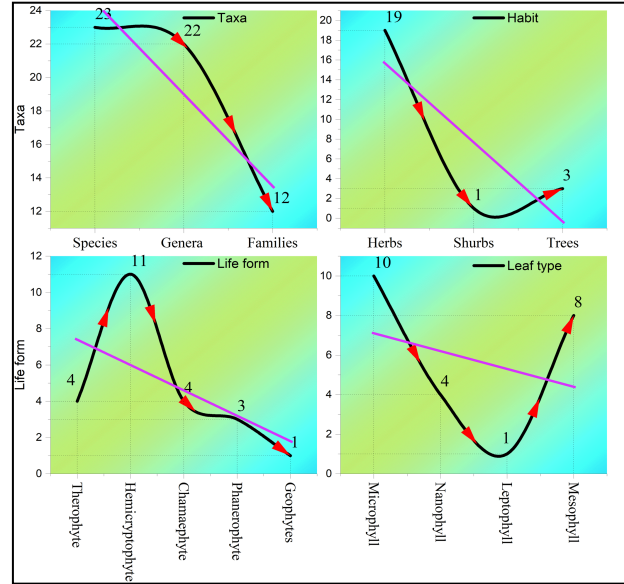


Fig. 7: Taxonomic and physiognomic characteristics of stand-4 in the study area

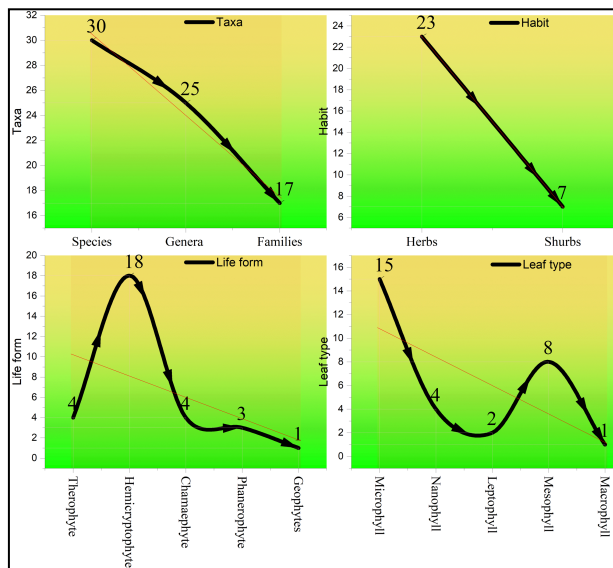


Fig. 6: Taxonomic and physiognomic characteristics of stand-3 in the study area

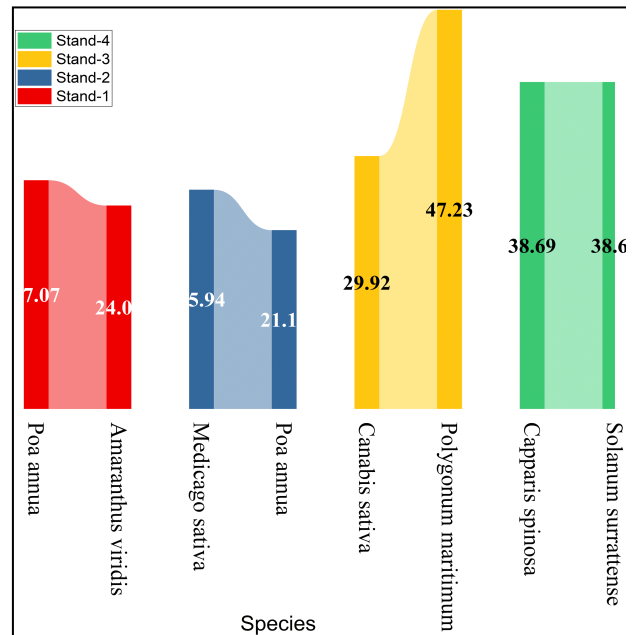


Fig. 8: Presents the top two species based on Importance Value Index (IVI) values across four stands in the study area

(IVI = 38.685) Fig. 8. The dominance of *Polygonum maritimum*, as indicated by its highest IVI value, underscores its critical ecological role within the community. Its prostrate, perennial, and semi-woody growth form contributes significantly to stabilizing the local ecosystem. By enhancing soil fertility and supporting species diversity, it fosters a more resilient environment. Its utility as fodder and occasional fuelwood highlights its socio-economic importance to local communities. Furthermore, its classification as a chamaephyte and its occurrence in cold climates mark it as an ecological indicator of harsh environmental conditions, emphasizing its

adaptation to stress. This multifaceted role positions *Polygonum maritimum* as a keystone species in its habitat. These species play vital roles in maintaining biodiversity, ecosystem stability, and soil health through their adaptive strategies.

K-means algorithm

The K-Means Cluster Analysis, based on the IVI (Importance Value Index) of species, revealed distinct

ecological patterns across the four stands. Stand 3 and Stand 4 emerge as critical in defining the clusters. The Elbow Method Plot Fig. 9 illustrates the Within-Cluster Sum of Squares (WCSS) as a function of cluster number. A clear inflection point at three clusters indicates the optimal number, balancing model complexity and explanatory power.

Cluster 1, which contains the most observations, is dominated by species from Stands 1 and 2, while Cluster 2 is influenced by the high Importance Value Index (IVI) contribution from Stand 4. The One-Way ANOVA results show highly significant differences for Stand 3 and 4 across clusters ($p < 0.0001$), emphasizing their importance in species distribution. Additionally, Principal Component Analysis (PCA) shows that PC1 explains the maximum variance, largely associated with species from Stand 3, while PC2 highlights variations from Stand 4, Fig. 10. These components reflect major axes of ecological differentiation, reinforcing the distinct clustering patterns. This analysis offers meaningful insights into the grouping of species based on their ecological significance across the stands.

Hierarchical clustering analysis of clusters

The distance between the final cluster centers in the hierarchical clustering analysis based on the IVI (Importance Value Index) of plant species across different ecological stands reveals clear distinctions between the three clusters. Cluster 1 and Cluster 2 are moderately separated by a distance of 15.26, suggesting some overlap in the environmental characteristics of species within these clusters. In contrast, Cluster 1 and Cluster 3 are more distinct, with a larger separation of 29.94, while the greatest difference is between Cluster 2 and Cluster 3 with a distance of 34.65, indicating that the species grouped in these clusters exhibit the most distinct ecological roles. This analysis highlights the hierarchical differentiation of species based on their IVI values, showing that Cluster 3 contains species, that are significantly different from those in Cluster 1 and Cluster 2, depicted in Fig. 11.

Pearson's correlation coefficient

The Pearson correlation is employed based on the Importance Value Index (IVI) to assess the relationships between species composition across different stands. The correlation values, such as -0.013 (Stand 1 vs Stand 2), -0.064 (Stand 1 vs Stand 3), and -0.148 (Stand 3 vs Stand 4), indicate weak or negligible linear relationships between the stands. This suggests that each stand hosts different species with distinct IVI values, highlighting the variation in species composition and dominance. The high p -values (e.g., 0.902 for Stand 1 vs Stand 2) further confirm that these correlations are statistically insignificant, emphasizing the ecological distinctiveness of each stand Fig. 12.

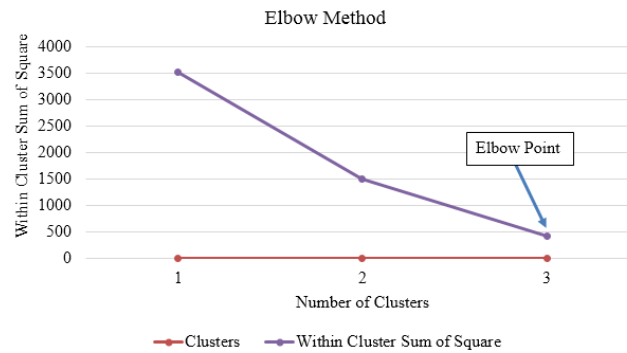


Fig. 9: Elbow Method for determining the optimal number of clusters based on the within-cluster sum of squares (WCSS)

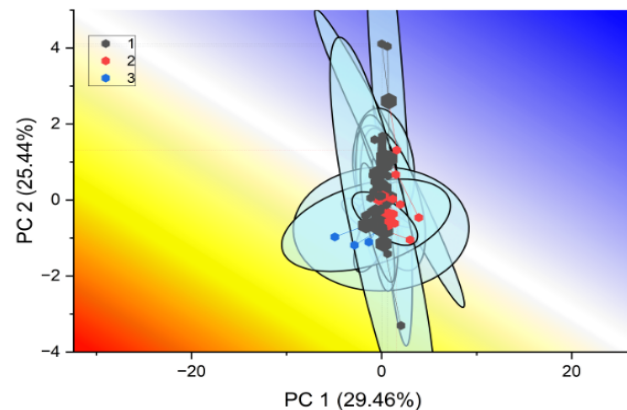


Fig. 10: K-Means and PCA reveal distinct ecological patterns based on IVI values of all stands

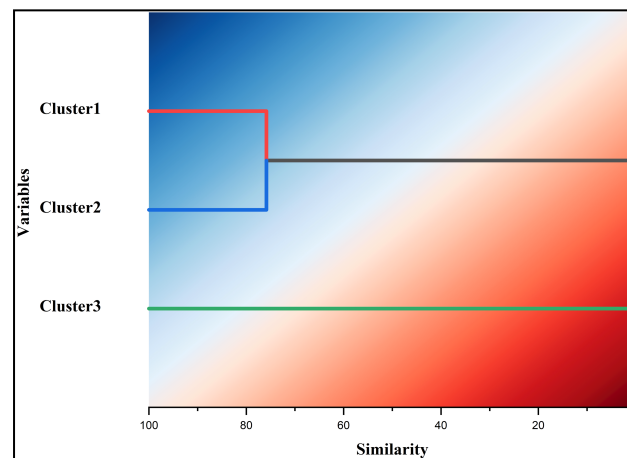


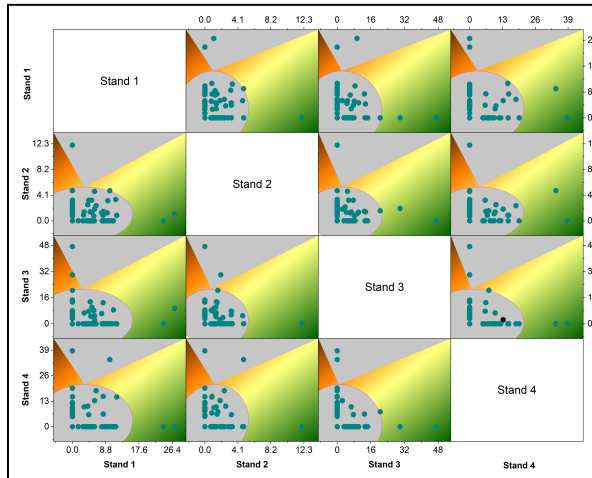
Fig. 11: The dendrogram shows distinct ecological groupings across the clusters, highlighting key separations in distinctiveness

Discussion

The Earth is undergoing a rapid decline in biodiversity, which disrupts ecosystem functions and the services it provides. In this context, phytosociology plays a crucial role in studying plant community structure, classification, and composition of the environment, thereby supporting

Table 2: Comparison of the biological spectrum of the study area with Raunkiaer's normal spectrum

Life Form	No. of Species	Study area's biological spectrum	Raunkiaer's normal spectrum %	Deviation
Phanerophytes	36	19.9	46	26.1
Chamaephytes	17	9.4	9	-0.4
Hemi-cryptophytes	74	40.9	26	-14.9
Geophytes	8	4.4	6	1.6
Therophytes	46	25.4	13	-12.4
Total	181			

**Fig. 12:** Pearson's correlation analysis shows weak relationships between stands, confirming their ecological distinctiveness

biodiversity conservation (Ali *et al.* 2022; Khadim *et al.* 2024). The current study focused on exploring the region's plant diversity and finding the biological spectrum and leaf type of the floral. The research revealed 181 distinct plant species, which followed 138 genera from 61 families.

The study delivers a comprehensive analysis of plant community structures and adaptive traits in four ecological stands, revealing distinct patterns of life forms, leaf size spectra, and species composition. The life form distribution in the study area deviates significantly from Raunkiaer's normal spectrum, indicating key adaptive strategies of the plant community to local environmental stress. The lower prevalence of phanerophytes (19.9%) in the study area highlights significant ecological constraints limiting the establishment of large woody plants. Factors such as poor soil fertility, extreme temperature variations, limited water availability, and habitat disturbance play a crucial role. Additionally, the study area's location along the narrow belt of the Karakoram Highway (KKH), dominated by rocky and hilly terrain, further restricts suitable conditions for the growth and survival of phanerophytes, reflecting the region's challenging environmental dynamics. In contrast, hemicryptophytes (40.9%) and therophytes (25.4%) exceed their expected values, reflecting adaptation to arid conditions and seasonal variability (Table 2). Hemicryptophytes thrive in harsh ecological conditions, particularly in temperate and arid climates. Their dominance

is driven by factors such as low temperatures, short growing seasons, drought, poor soil quality, and shallow soil depth. Reduced competition, along with grazing pressures and herbivory, further promote their survival. Moreover, genetic adaptations and phylogenetic history enhance their ability to cope with environmental stresses. These traits enable hemicryptophytes to outcompete other plant species in challenging ecosystems (Khan *et al.* 2013). These shifts emphasize the role of local environmental factors in shaping plant communities and underscore the need for targeted conservation strategies to maintain biodiversity in areas impacted by climate change and human activities.

In phytosociological studies, the dominance of hemicryptophytes, especially in Stand 1 (45%) and Stand 3 (60%), highlights their ecological significance in arid environments, where they play a critical role in withstanding temperature fluctuations and conserving water. Grime (2001) first suggested the resilience of hemicryptophytes under stress conditions. Hemicryptophytes' prevalence suggests they are keystone species in sustaining plant diversity and functioning in harsh environments. The documented flora was classified into different leaf types according to their size by Raunkiaer (1934). An abundance of microphyllous species in this study, particularly in Stand 1 (40%) and Stand 3 (50%), indicates their adaptive advantage in reducing water loss in dry conditions. This observation is consistent with recent work by Garcia *et al.* (2022), who noted similar leaf size patterns in Mediterranean climates. Ali *et al.* (2016) found that microphylls were the dominant leaf size class in Chail Valley, Swat, and Sherpao, District Charsadda. Followed by Khan *et al.* (2014) also reported microphylls as predominant, a trend also seen in Shahbaz Garhi, District Mardan. Moreover, (Liu *et al.* 2020) highlighted the adaptive significance of microphylls in high-altitude arid regions, demonstrating that these small-leaved plants thrive under limited water availability. The ecological significance of this finding is profound, as it underscores the importance of leaf traits in plant survival and ecosystem functioning in water-scarce environments. Furthermore, these plants hold significant ecological importance. Their small leaf size minimizes water loss, offers protection against extreme winds, and utilizes snow cover as natural insulation, preserving vital warmth. Additionally, their efficient nutrient uptake mechanisms are finely tuned to the resource-scarce environment. These adaptations not only ensure their survival but also serve as ecological indicators of the

prevailing cold and harsh climatic conditions, reflecting their unique resilience and critical role in such ecosystems.

The K-Means Cluster Analysis and PCA revealed distinct ecological differentiation between the stands, particularly between Stands 3 and 4, which played a critical role in shaping the clusters. Stand 3, contributing to the most distinct cluster, exhibited the greatest separation from other clusters (29.94), indicating unique ecological conditions, potentially driven by altitude, slope, or soil characteristics. This pattern parallels findings from Berveglieri *et al.* (2021), who also reported strong spatial heterogeneity in plant communities across altitudinal gradients. In addition, a study by Zu *et al.* (2023) supports the idea that species distributions in arid ecosystems are strongly influenced by micro-environmental factors, reinforcing the significance of stand-specific diversity. Such ecological differentiation is crucial for understanding the distribution of biodiversity and identifying conservation priorities in fragmented habitats.

Weak Pearson correlations between stands (e.g., -0.013 between Stand 1 and Stand 2) reflect the minimal species overlap across stands, highlighting the high degree of local adaptation to specific environmental conditions. This weak inter-stand correlation is consistent with Rahbek (1995), who also found low species similarity across different climatic and topographic gradients. The weak Pearson correlations between stands reflect stark ecological contrasts, emphasizing how localized environmental factors shape plant communities. Some stands are barren and rocky, with limited vegetation due to poor soil fertility and harsh microclimatic conditions, while others support richer vegetation due to favorable soil quality, better moisture retention, and nutrient availability. The distinctiveness of each stand's species composition highlights the significant role of these environmental pressures, reinforcing the need for targeted, localized conservation efforts to preserve biodiversity (Jean *et al.* 2015). The significance of this finding lies in promoting biodiversity through spatial heterogeneity, which enhances ecosystem resilience in fluctuating environments.

The significant One-Way ANOVA ($p < 0.0001$) results highlighted ecological differences between Stand 3 and Stand 4, shaped by contrasting environmental conditions. Stand 3, with its favorable soil and vegetation, supports greater species diversity due to enhanced moisture retention and nutrient availability. In contrast, stand 4, defined by its rocky and barren terrain, exhibits lower species diversity because of limited resources. These findings underscore the role of topography, soil quality, and microclimatic factors in determining species richness and ecological functions, emphasizing the critical importance of habitat quality in biodiversity conservation (Khan *et al.* 2013). Similar findings by Ma *et al.* (2015) demonstrated that certain stands in fragmented ecosystems play disproportionate roles in maintaining biodiversity, emphasizing the need for targeted conservation strategies. Zu *et al.* (2023) also stressed that preserving such

ecologically unique stands is crucial for maintaining plant diversity, particularly in ecosystems vulnerable to climate change and anthropogenic pressures. Including more than four stands beyond the study area may influence the current findings by altering the clustering analysis outcomes due to variations in altitude, microclimatic conditions, soil types, vegetation composition, and anthropogenic pressures, which could introduce additional complexity to the analysis. However, all stands exhibited distinct species compositions, predominantly herb-dominated, with hemicryptophytes as the prevailing life form, reflecting cold climatic conditions consistent with the region's climate.

Conclusion

This study underscores the importance of plant community structures, life forms, and adaptive traits in arid, fragmented environments, highlighting the dominance of hemicryptophytes and microphyll species, which are critical for maintaining biodiversity and ecosystem functions under stress. The distinct ecological differentiation between stands, particularly Stands 3 and 4, reveals how localized environmental factors shape plant communities. The weak species overlap and highly significant ANOVA results suggest a need for targeted, site-specific conservation strategies to protect biodiversity hotspots. However, human activities such as road construction, mining, and land use changes are accelerating habitat fragmentation, and threatening ecosystem sustainability. These findings highlight the urgency for conservation measures focused on preserving unique ecological niches and ensuring ecosystem resilience in the face of climate change and anthropogenic pressures.

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Author Contributions

RA led the research, with SWK and SH in a supervisory role. MH, WH, and FH assisted in data collection, and SK provided continuous support throughout the research process, from manuscript drafting to final approval. Each member's expertise was crucial to our success.

Conflicts of Interest

The authors of this paper declare no conflict of interest.

Data Availability

The corresponding author will provide access to the data from this study upon a justifiable request.

Ethical Approval

Not applicable to this paper.

References

- Abbas H, H Ali, SW Khan, S Khadim (2024). Ethnobotanical applications of medicinal plants in the alpine flora of Marukh and Asogaha Nallah, Haramosh Valley, District Gilgit, Pakistan. *Ethnobot Res Appl* 13:1–24
- Abbas Q, A Hussain, SW Khan, A Hussain, S Shinwari, A Hussain, A Ullah, M Zafar, K Ali (2019). Floristic diversity, ethnobotany, and traditional recipes of medicinal plants of Marukh Nallah, Haramosh Valley, District Gilgit, Gilgit Baltistan. *Proc Pak Acad Sci* 56:97–112
- Ali MA, MS Iqbal, KS Ahmad, M Akbar, A Mehmood, SA Hussain, N Arshad, S Munir, H Masood, T Ahmad (2022). Plant species diversity assessment and monitoring in catchment areas of River Chenab, Punjab, Pakistan. *PLoS One* 17:e0272654
- Ali S, M Shuaib, H Ali, S Ullah, K Ali, S Hussain, N Hassan, U Zeb, WM Khan, F Hussain (2016). Floristic list and their ecological characteristics of plants at village Sherpao, District Charsadda, KP-Pakistan. *J Med Plants Stud* 5:295–299
- Ali SI, M Qaiser (1986). A phytogeographical analysis of the phanerogams of Pakistan and Kashmir. *Proc R Soc Edinb, Sect B Biol Sci* 89:89–101
- Antongiovanni M, EM Venticinque, M Matsumoto, CR Fonseca (2020). Chronic anthropogenic disturbance on Caatinga dry forest fragments. *J Appl Ecol* 57:2064–2074
- Badshah L, F Hussain, Z Sher (2013). Floristic Inventory, Ecological Characteristics and Biological Spectrum. *Pak J Bot* 45:1159–1168
- Batalha MA, FR Martins (2002). Life-form spectra of Brazilian cerrado sites. *Flora* 197:452–460
- Berveglieri A, NN Imai, AM Tommaselli, RP Martins-Neto, GT Miyoshi, E Honkavaara (2021). Forest cover change analysis based on temporal gradients of the vertical structure and density. *Ecol Indic* 126:107597
- Cain SA, GMD Castro (1959). *Manual of Vegetation Analysis*, p:55. Harper press, New York, USA
- Curtis JT, RP McIntosh (1951). An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 32:476–496
- Grime JP (2001). *Plant Strategies, Vegetation Processes, and Ecosystem Properties*, 2nd edn. John Wiley & Sons, New York, USA
- Gul B, I Ahmad, H Khan, U Zeb, H Ullah (2018). Floristic inventory of wild plants of Peshawar University campus. *Acta Ecol Sin* 38:375–380
- Haider S, N Ibrahim (2022). Ecological Significance of floristic structure and Biological Spectrum of alpine floral biodiversity of Khunjerab National Park Gilgit-Baltistan Pakistan. *Intl J Innov Sci Technol* 4:564–577
- Hassan A, G Samy, M Hegazy, A Balah, S Fathy (2024). Statistical analysis for water quality data using ANOVA (Case study – Lake Burullus influent drains). *Ain Shams Eng J* 15:102652
- Hussain W, L Badshah, F Hussain, A Ali (2020). Floristic configuration and ecological characteristics of plants of Koh-e-Safaid range, northern Pakistani-Afghan borders. *Acta Ecol Sin* 40:221–236
- Jean HB, LA Brian, YS Sharon, JB David (2015). Soil microbial community variation correlates most strongly with plant species identity, followed by soil chemistry, spatial location and plant genus. *AoB Plants* 7:plv030
- Jiménez-Preciado, AL, S Cruz-Aké, F Venegas-Martínez (2024). Identification of patterns in CO2 emissions among 208 countries: K-means clustering combined with PCA and non-linear t-SNE visualization. *Mathematics* 12:2591
- Karima, S Hyder, S Khadim, N Zehra, Shahnaz, Zeshan, R Ali, A Abbass (2024). Analyzing phytoecological significance of floral biodiversity in Rahim Abad, District Gilgit, Pakistan. *Intl J Agric Biol* 31:235–242
- Kent M, P Coker (1992). *Vegetation Description and Data Analysis: A Practical Approach*. John Wiley & Sons, Chichester, UK
- Khadim S, H Sujjad, Z Tehseen, A Hasnain (2024). Ethnobotanical inventory and indigenous therapeutic applications of wild medicinal plants in Parishing Valley, District Astore, Gilgit-Baltistan, Pakistan. *Ethnobot Res Appl* 28:1–26
- Khadim S, S Hyder, AA Shedayi, T Zuhra, K Ali (2024). Diversity of the herbaceous flora and their indigenous medicinal uses at Theeing Valley, District Astore, Gilgit-Baltistan, Pakistan. *Ethnobot Res Appl* 27:1–28
- Khan M, F Hussain, S Musharaf (2013). Ecological dynamics of vegetation in temperate regions of northern Pakistan. *J Plant Ecol* 15:125–135
- Khan M, F Hussain, S Musharaf (2014). Floristic composition and ecological characteristics of Shahbaz Garhi, District Mardan, Pakistan. *Glob. J. Sci. Front Res Biol Sci* 14:1–7
- Liu W, L Zheng, D Qi (2020). Variation in leaf traits at different altitudes reflects the adaptive strategy of plants to environmental changes. *Ecol Evol* 10:8166–8175
- Ma L, M Huang, Y Shen, H Cao, L Wu, H Ye, G Lin, Z Wang (2015). Species diversity and community structure in forest fragments of Guangzhou, South China. *J Trop For Sci* 27:148–157
- Macêdo MS, BS Menezes, MP Ledru, J Mas, FKG Silva, CE Carvalho, RC Costa, RB Zandavalli, AA Soares, FS Araújo (2024). Everything's not lost: Caatinga areas under chronic disturbances still have well-preserved plant communities. *J. Arid Environ* 222:105164
- Manan F, SM Khan, Z Muhammad, Z Ahmad, A Abdullah, AUR Rahman, H Han, A Ariza-Montes, N Contreras-Barraza, A Raposo (2022). Floristic composition, biological spectrum, and phytogeographic distribution of the Bin Dara Dir, in the western boundary of Pakistan. *Front For Glob Change* 5:1019139
- Rahbek C (1995). The elevational gradient of species richness: a uniform pattern? *Ecography* 18:200–205
- Raunkiaer C (1934). *The life forms of plants and statistical plant geography: being the collected papers of C. Raunkiaer*. Clarendon Press, Oxford, UK
- Shahab Ud Din, Q Abbas, S Khadim, P Abbas, H Abbas, T Zuhra, MA Irfani (2024). Ethnobotanical inventory and traditional medicinal applications of the flora in Kutwal Haramosh Valley, District Gilgit, Pakistan. *Ethnobot Res Appl* 13:1–26
- Sintayehu DW (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: A systematic review. *Ecosys. Heal Sustain* 4:225–239
- Vaish R, UD Dwivedi, S Tewari, SM Tripathi (2021). Machine learning applications in power system fault diagnosis: Research advancements and perspectives. *Eng Appl Artif Intell* 106:104504
- Young HS, DJ McCauley, M Galetti, R Dirzo (2016). Patterns, causes, and consequences of anthropocene defaunation. *Annu Rev Ecol Evol Syst* 47:333–358
- Zehra N, S Hyder, S Khadim, M Zeeshan, R Ali, A Abbas, Shahnaz, Karima (2024). The phytoclimatic spectrum of weed flora of Nomal Valley, District Gilgit, Gilgit-Baltistan, Pakistan. *Intl J Agric Biol* 32:136–144
- Zu K, JRMH Lenoir, J Fang, Z Tang, Z Shen, C Ji, C Zheng, A Luo, W Song, N Zimmermann, L Pellissier, Z Wang (2023). Elevational shift in seed plant distributions in China's mountains over the last 70 years. *Glob Ecol Biogeogr* 32:1098–1112