Microclimate Interactions and Mapping the Diversity and Distribution of Monocotyledonous Plants and Ferns: Ecological Insights and Conservation Implications

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ABSTRACT

Plant biodiversity in terms of monocotyledonous species and ferns remains underexplored in many regions, despite its critical role in ecosystem stability and conservation efforts. This study addresses the gap by exploring the biodiversity and ecological distribution of these plant groups. This study aims to document the diversity, distribution, and ecological characteristics of monocotyledonous plants and ferns to inform conservation planning and sustainable resource utilization. Two distinct experiments were conducted. The first focused on monocotyledonous flora, identifying 156 species from 95 genera and 20 families, with Poaceae being the most dominant. The second study evaluated the distribution of ferns and fern-allies, identifying 81 taxa from 30 genera and 18 families, through extensive field surveys and a literature review. Poaceae dominated the monocotyledonous flora, and several fern species had significant medicinal and nutritional value. The distribution of both groups was influenced by elevation, slope, aspect, and moisture. Phytogeographical analysis indicated that Western Himalayan elements were the most prevalent in the monocotyledonous flora. The findings underscore the ecological significance of these plant groups, offering valuable insights for biodiversity conservation strategies, ecological evaluation, and sustainable land-use planning. The study is limited by the geographic focus on monocotyledons and ferns, leaving other plant groups underrepresented. Additionally, the study’s field surveys were limited to specific elevation ranges and may not capture the full extent of biodiversity across the region. Future research should expand the scope to include other plant families and explore the impacts of climate change on plant distributions. Further studies could also investigate the genetic diversity of these plant groups. The results provide a strong foundation for evidence based decision-making in conservation, offering an essential resource for botanists, ecologists, and conservation biologists in their efforts to protect and manage plant diversity. Overall, this research contributes to filling existing floristic knowledge gaps in the Western Himalayan region and supports the development of region-specific conservation frameworks.

Key words: Flora of Muzaffarabad, Monocotyledonous plants, Pteridophytes, Species diversity, Phytogeographical distribution, Western Himalaya.

1. Introduction

Biodiversity is a critical aspect of ecosystem stability, with various plant groups playing essential roles in maintaining ecological balance. Monocotyledonous plants and ferns, in particular, contribute significantly to the functioning of ecosystems but remain underexplored in many regions. Understanding their diversity and distribution is crucial for informed conservation strategies and sustainable resource management. Angiosperms or flowering plants represent the largest and most diverse group in the plant kingdom, comprising approximately 375,000 species across around 13,000 genera, 416 families, and 64 orders. Notably, they account for more than 80% of all green plants. This diverse group includes herbs, shrubs, trees, and vines, which dominate terrestrial vegetation in tropical rainforests, temperate forests, and grasslands. Monocotyledons (monocots) form one of the major evolutionary lineages of angiosperms and represent approximately one fourth of all flowering plant species [1, 2]. Recognized as a monophyletic clade, monocots originated early within the angiosperm radiation and have diversified significantly across geologic time, with major family-level radiations occurring during the Early Cretaceous [3–5]. Monocots are characterized by features such as a single cotyledon, parallel venation, scattered vascular bundles, and floral parts in multiples of three. These plants play vital ecological and economic roles, stabilizing habitats, improving soil, providing forage for livestock, and offering essential resources for insects, birds, and animals. They are also indispensable to humans for food production, shelter, clothing, and medicine.

This study aims to fill a crucial gap by exploring and documenting the diversity, distribution, and ecological characteristics of monocotyledonous plants and ferns. By providing insights into these plant groups, the study contributes to enhancing biodiversity conservation efforts, particularly in sensitive and under-researched regions. With around 60,000 species globally, monocots include families with immense agricultural and ornamental value such as Poaceae (grasses), Orchidaceae (orchids), Arecaceae (palms), Amaryllidaceae (onions, garlic), Musaceae (bananas), and Zingiberaceae (gingers) [6,2]. Major staple crops like rice, wheat, and maize, as well as sugarcane, bamboo, leeks, turmeric, and cardamom, are monocots, contributing significantly to global food security and economic stability [7, 8]. Monocots are distributed worldwide, occupying habitats from temperate grasslands to tropical rainforests. Their distribution reflects strong relationships with biotic and abiotic environmental gradients such as climate, topography, soil, and geological history [9, 10]. Understanding these spatial patterns is essential for ecological assessments, conservation strategies, and biodiversity management [11, 12]. Floristic inventories are vital tools for analyzing plant diversity, mapping species distributions, and identifying phytogeographic elements [13, 14]. They provide insight into vegetation composition, ecosystem function, and species–environment relationships [15–17]. Phytogeographic classification helps reveal evolutionary, ecological, and migrational patterns of taxa across regions [18, 19].

The study employed two distinct methods: field surveys to document monocotyledonous and fern species and a comprehensive literature review for further ecological insights. A total of 156 monocot species and 81 fern taxa were identified across various genera and families, with a particular focus on the dominant families, Poaceae for monocots and Dryopteridaceae for ferns. Pteridophytes, also known as vascular cryptogams, represent the third-largest group of vascular plants, with about 12,838 taxa across 58 families and 19 orders [20]. These spore-producing plants are evolutionarily ancient, dating back over 400 million years [21], and occupy habitats from tropical rainforests to alpine zones, with species richness increasing toward the equator [22,23]. Many pteridophytes are epiphytic and contribute significantly to forest ecosystems, although overall speciation and endemism are relatively low [24]. They are evolutionarily positioned as sister groups to seed-bearing plants and thus hold great value in studies of plant evolution and phylogeny [25]. They are also distinguished from other vascular plants by their free-living and nutritionally independent sporophyte and gametophyte generations [26, 27].

Pteridophytes contribute significantly to ecological processes such as nutrient cycling, soil stabilization, and habitat structuring. Several fern species act as bioindicators for habitat disturbance, soil degradation, and climate variability. Species such as *Pteridium aquilinum*, *Asplenium*, and *Adiantum* are commonly used to assess environmental quality [28]. Additionally, ferns like *Pteris vittata* have been found to hyperaccumulate heavy metals and are therefore used in phytoremediation to clean contaminated soil and air [29, 30]. Ethnomedicinally, species such as *Adiantum*, *Pteris*, and *Lygodium* are widely used to treat gastrointestinal disorders, wounds, fevers, ulcers, hypertension, and bone fractures [31, 32]. *Azolla*, a floating aquatic fern, is cultivated in rice fields as a biofertilizer due to its symbiotic nitrogen-fixing cyanobacteria *Anabaena azollae* [33]. Other ornamental ferns like *Nephrolepis* and *Adiantum* are valued for their beauty, while *Dryopteris filix-mas* is used medicinally as an anthelmintic [34, 35]. Interestingly, the presence of *Equisetum* has also been associated with gold-rich soils in some studies [36].

Biodiversity is unevenly distributed across the globe, and understanding its underlying drivers remains a central focus in ecology, evolution, and biogeography [37]. Within vascular plants, pteridophytes including both ferns and lycophytes constitute the second most diverse group. Today, this group comprises approximately 11,000 extant species [38], and their unique biology and ecological significance make them essential to evolutionary, floristic, and ecological research.

Despite their global significance, both monocots and pteridophytes remain understudied in several regions. This research highlights the floristic richness of monocotyledonous plants and ferns, revealing new insights into their distribution and ecological roles. The study underscores the importance of these plant groups for biodiversity conservation, especially in areas vulnerable to habitat degradation and climate change. However, the geographic focus is limited, and further studies are needed to explore other plant families and the impacts of climate change on their distributions. The Himalayas, including Azad Jammu and Kashmir, are biodiversity-rich due to habitat heterogeneity, elevation gradients, and climatic variation. However, comprehensive floristic surveys remain sparse. Stewart [39] compiled one of the earliest floristic lists for western Pakistan and Azad Kashmir. In recent decades, localized floristic checklists have been prepared for areas like Kotli [40, 41], Nikyal [42], Rawalakot [43], Dhirkot [44], and Neelum [45]. A more comprehensive checklist was produced for District Muzaffarabad [8]. Nevertheless, a unified, detailed floristic account of monocot and pteridophyte diversity for District Muzaffarabad remains lacking, necessitating updated and region-specific taxonomic documentation. The objective of this study was to develop a comprehensive checklist and evaluate the taxonomic diversity, distribution patterns, phytogeographical affinities, ecological characteristics, and conservation status of monocotyledonous plants and Pteridophytes in District Muzaffarabad, Azad Jammu and Kashmir.

2. Materials and Methods

Study Area

Two separate experiments were conducted in District Muzaffarabad, the capital of Azad Jammu and Kashmir (AJK), located in the western Himalayan region of Pakistan. The district spans an area of 1,642 km², lying between 34°20́ N latitude and 73°30́ E longitude, with an altitudinal range of 700 m to 4500 m. The area comprises steep mountains, river valleys, alpine pastures, and forested slopes. The district is enriched by three main rivers Neelum, Kunhar, and Jhelum and experiences diverse climatic conditions ranging from subtropical in lowlands to alpine in upper reaches. This environmental diversity provides a wide range of habitats suitable for a variety of plant life including monocots, ferns, and fern-allies.

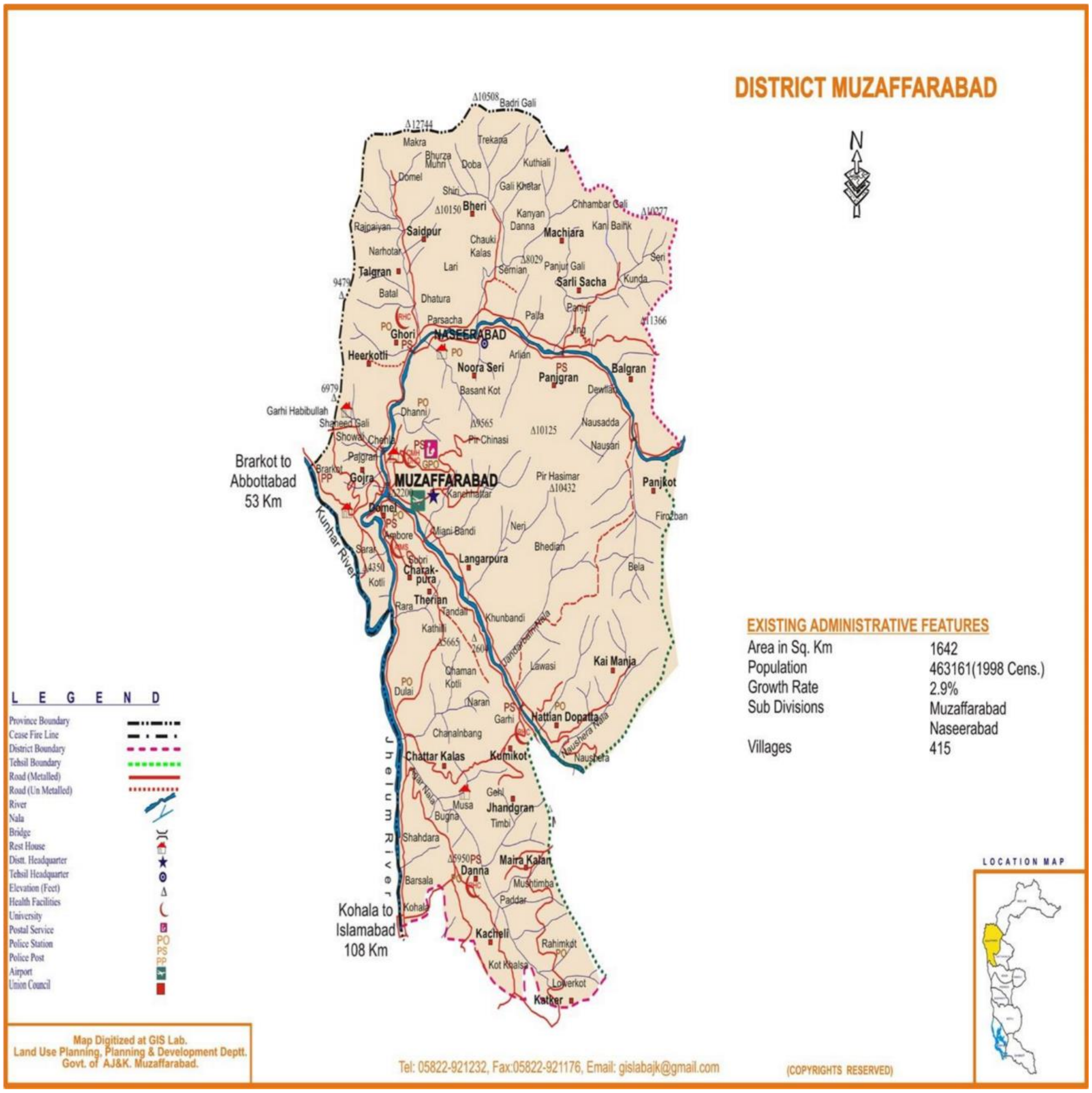

Figure 1. Map of study area district Muzaffarabad, Azad Jammu and Kashmir

2.1 Methodology of Experiment-1: Monocotyledonous Flora

Field Surveys and Plant Collection

In order to study the monocotyledonous plants of District Muzaffarabad, field studies were conducted from June 2022 to June 2023, in various seasons to record the maximum floristic diversity of monocotyledons. Muzaffarabad, the capital of Azad Jammu and Kashmir, is located at an altitude of approximately 737 meters above sea level**,** positioned at 34.3700° North latitude and 73.4700° East longitude**.** Plant specimens were collected using standard herbarium techniques, including pressing and drying, and later mounted on herbarium sheets.

Identification and Classification

The specimens were identified using classical literature including Stewart [39], *Flora of Pakistan* [46,47], and modern taxonomic databases like WFO, IPNI, POWO and TROPICOS. APG-IV classification was followed, and validated names were confirmed via World Flora Online (WFO) [48]. All validated specimens were deposited in the AKASH Herbarium, University of AJK, and digitized in Open Herbarium for GBIF.

Microhabitat Classification

Microhabitats were classified according to Khan et al. [8], and included locations such as sandy/loamy soils, marshy places, grassy meadows, rocky crevices, forest margins, and more.

Life Form Categorization

Life forms were categorized following Raunkiaer's system [49] and Hussain [50]:

- Therophytes
- Geophytes
- Hemicryptophytes
- Chamaephytes
- Phanerophytes (further divided into Nanophanerophytes and Megaphanerophytes)

Phytogeographical Analysis

Geographical distribution was analyzed using references such as Stewart [39], Polunin and Stainton [51], and Takhtajan [5]. Species were grouped according to their biogeographic affinities: Western Himalayan, Eurasian, Cosmopolitan, Endemic, etc.

3. Methodology of Experiment-2: Ferns and Fern-Allies

Field Collection

Systematic collection of ferns and fern-allies was carried out during 2022–2023 across all 28 union councils of District Muzaffarabad. Specimens were pressed and preserved using standard techniques. Field data included frond characteristics, sori patterns, and microhabitat types.

Identification and Herbarium Work

Specimens were identified using classical fern literature (e.g., Beddome, Stewart, Copeland, Dixit) and verified through taxonomic databases (IPNI, TROPICOS, WFO). Specimens were mounted, labeled, and deposited at AKASH Herbarium and digitized on Open Herbarium.

Phytogeographical Affinities

Floristic classification was performed using Takhtajan's global floristic regions [5] and other sources [52]. Species were assigned to appropriate phytogeographic zones.

Conservation Status

Abundance and rarity of each species were assessed using IUCN Red List criteria (2022–2023). Ferns were categorized based on local population sizes and field observations.

Distribution and GIS Mapping

Species locations were georeferenced using GPS (Garmin 12) and visualized using ArcGIS 10.4. Historical presence and current status were compared to assess changes in range or abundance.

Ethnobotanical Data

Ethnobotanical information was collected via semi-structured interviews and questionnaires [53]. Parameters such as Use Value (UV), Informants Consensus Factor (ICF), Fidelity Level (FL), and Relative Frequency of Citation (RFC) were calculated as per standard ethnobotanical methods [54, 55].

4. Results

Microclimate Variation and Taxonomic Diversity

The present study, conducted from July 2022 to August 2023, aimed to document the monocotyledonous flora of District Muzaffarabad, AJK. A total of 156 monocot species belonging to 95 genera and 20 families across 8 orders were recorded. The order Asparagales was the most dominant, represented by 5 families, followed by Poales and Liliales with 4 families each. The five leading families contributing 80% of species were Poaceae (66 species), Cyperaceae (31 species), Orchidaceae (18 species), Asparagaceae (6 species), and Araceae (5 species). Poaceae was the most diverse, followed by Cyperaceae and Orchidaceae. Among genera, Agrostis, Bromus (Poaceae), and Herminium (Orchidaceae) were the most diverse, each with 4 species.

Table.1 Taxonomic diversity of plant species with in order Poales comprising families Poaceae, Cyperaceae, Juncaceae and Typhaceae

Sr No	Plant Species Name	Families
1	*Bambusa multiplex* (Lour.) Raeusch. ex Schult.f.	Poaceae
2	*Agrostis canina* L.	Poaceae
3	*Agrostis capillaris* L.	Poaceae
4	*Agrostis munroana* Aitch. & Hemsl.	Poaceae
5	*Agrostis vinealis* Schreb.	Poaceae
6	*Aristida abnormis* Chiov.	Poaceae
7	*Aristida adscensionis* L.	Poaceae
8	*Aristida cyanantha* Steud.	Poaceae
9	*Aristida funiculata* Trin. & Rupr.	Poaceae
10	*Aristida mutabilis* Trin. & Rupr.	Poaceae
11	*Arthraxon lancifolius* (Trin.) Hochst.	Poaceae
12	*Arundo donax* L.	Poaceae
13	*Avena barbata* Pott ex Link	Poaceae
14	*Avena fatua* L.	Poaceae
15	*Bothriochloa bladhii* (Retz.) S.T.Blake	Poaceae
16	*Bothriochloa ischaemum* (L.) Keng	Poaceae
17	*Bothriochloa pertusa* (L.) A.Camus	Poaceae
18	*Brachypodium sylvaticum* (Huds.) P.Beauv.	Poaceae
19	*Bromus catharticus* Vahl	Poaceae
20	*Bromus japonicus* Houtt.	Poaceae
21	*Bromus lanceolatus* Roth	Poaceae
22	*Bromus pectinatus* Thunb.	Poaceae
23	*Capillipedium assimile* (Steud.) A.Camus	Poaceae
24	*Capillipedium parviflorum* (R.Br.) Stapf	Poaceae
25	*Cenchrus biflorus* Roxb.	Poaceae
26	*Cenchrus ciliaris* L.	Poaceae
27	*Cenchrus pennisetiformis* Steud.	Poaceae
28	*Chrysopogon gryllus* (L.) Trin.	Poaceae
29	*Chrysopogon serrulatus* Trin.	Poaceae
30	*Cymbopogon distans* (Nees ex Steud.) W.Watson	Poaceae
31	*Cymbopogon martini* (Roxb.) W.Watson	Poaceae
32	*Cymbopogon pospischilii* (K.Schum.) C.E.Hubb.	Poaceae
33	*Cynodon dactylon* (L.) Pers.	Poaceae
34	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae
35	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae
36	*Digitaria nodosa* Parl.	Poaceae

37	*Digitaria pennata* (Hochst.) T.Cooke	Poaceae
38	*Eleusine indica* (L.) Gaertn.	Poaceae
39	*Eragrostis cilianensis* (All.) Vignolo ex Janch.	Poaceae
40	*Eragrostis japonica* (Thunb.) Trin.	Poaceae
41	*Helictochloa pratensis* (L.) Romero Zarco	Poaceae
42	*Imperata cylindrica* (L.) P.Beauv.	Poaceae
43	*Lolium temulentum* L.	Poaceae
44	*Oplismenus compositus* (L.) P.Beauv.	Poaceae
45	*Oplismenus undulatifolius* (Ard.) P.Beauv.	Poaceae
46	*Oryza sativa* L.	Poaceae
47	*Panicum miliaceum* L.	Poaceae
48	*Paspalum scrobiculatum* L.	Poaceae
49	*Phalaris minor* Retz.	Poaceae
50	*Phleum alpinum* L.	Poaceae
51	*Phleum paniculatum* Huds.	Poaceae
52	*Phleum pratense* L.	Poaceae
53	*Poa angustifolia* L.	Poaceae
54	*Poa annua* L.	Poaceae
55	*Poa bactriana* Roshev.	Poaceae
56	*Poa nemoralis* L.	Poaceae
57	*Poa pratensis* L.	Poaceae
58	*Polypogon fugax* Nees ex Steud.	Poaceae
59	*Polypogon monspeliensis* (L.) Desf.	Poaceae
60	*Saccharum spontaneum* L.	Poaceae
61	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae
62	*Setaria viridis* (L.) P.Beauv.	Poaceae
63	*Sorghum bicolor* (L.) Moench	Poaceae
64	*Stipa himalaica* Roshev.	Poaceae
65	*Triticum aestivum* L.	Poaceae
66	*Zea mays* L.	Poaceae
67	*Blymus compressus* (L.) Panz.ex Link	Cyperaceae
68	*Bulbostylis barbata* (Rotb.)C.B.Clark	Cyperaceae
69	*Carex atrata subsp.pullata* (boott) Kuk	Cyperaceae
70	*Carex breviculmis* R.Br	Cyperaceae
71	*Carex brunnea* Thunb.	Cyperaceae
72	*Carex canescens* L.	Cyperaceae
73	*Carex nubigena* D.Don	Cyperaceae
74	*Carex songorica* Kar.& Kir	Cyperaceae

75	*Carex taldycola* Meinsh	Cyperaceae
76	*Cladium mariscus* (L) Pohl	Cyperaceae
77	*Cyperus arenarius* Retz.	Cyperaceae
78	*Cyperus cyperoides* (L.) Kuntze	Cyperaceae
79	*Cyperus difformis* L.	Cyperaceae
80	*Cyperus dubius* Rottb.	Cyperaceae
81	*Cyperus iria* L.	Cyperaceae
82	*Cyperus laevigatus* L.	Cyperaceae
83	*Cyperus niveus* Retz.	Cyperaceae
84	*Cyperus pilosus* Vahl	Cyperaceae
85	*Cyperus rotundus* L.	Cyperaceae
86	*Cyperus serotinus* Rottb.	Cyperaceae
87	*Cyperus squarrosus* L.	Cyperaceae
88	*Cyperus stoloniferus* Retz.	Cyperaceae
89	*Erioscirpus comosus* (Wall.) Palla	Cyperaceae
90	*Fimbristylis dichotoma* (L.) Vahl	Cyperaceae
91	*Kobresia duthiei* C.B.Clarke	Cyperaceae
92	*Kobresia humilis* (C.A.Mey.ex Trautv.)Serg.	Cyperaceae
93	*Kobresia nepalensis* (Nees) Kuk.	Cyperaceae
94	*Kyllinga brevifolia* Rottb.	Cyperaceae
95	*Kyllinga nemoralis* (J.R.Forst. & G.Forst.)	Cyperaceae
96	*Pycerus pumilus* (L.) Nees	Cyperaceae
97	*Scirpoides holoschoenus* (L.) Sojak	Cyperaceae
98	*Juncus bufonius* L.	Juncaceae
99	*Typha latifolia* L.	Typhaceae

Table 2. List of species recorded under the order Asparagales represented by Amaryllidaceae, Asparagaceae, Asphodelaceae, Iridaceae and Orchidaceae

Sr No	Plant Species Name	Families
1	*Allium cepa* L.	Amaryllidaceae
2	*Allium jacquemontii* Kunth	Amaryllidaceae
3	*Allium sativum* L.	Amaryllidaceae
4	*Narcissus tazetta* L.	Amaryllidaceae
5	*Asparagus adscendens* Roxb.	Asparagaceae

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6	*Asparagus officinalis* L.	Asparagaceae
7	*Aspidistra sichuanensis* K.Y.Lang	Asparagaceae
8	*Cordyline fruticosa* (L.) A.Chev.	Asparagaceae
9	*Liriope graminifolia* (L.) Baker	Asparagaceae
10	*Polygonatum multiflorum* (L.) All.	Asparagaceae
11	*Aloe vera* (L.) Burm.f.	Asphodelaceae
12	*Asphodelus tenuifolius* Cav.	Asphodelaceae
13	*Eremurus persicus* (Jaub. & Spach) Boiss.	Asphodelaceae
14	*Crocus sativus* L.	Iridaceae
15	*Iris hookeriana* Foster	Iridaceae
16	*Cephalanthera longifolia* (L.) Fritsch	Orchidaceae
17	*Cypripedium cordigerum* D.Don	Orchidaceae
18	*Dactylorhiza hatagirea* (D.Don) Soó	Orchidaceae
19	*Dienia cylindrostachya* Lindl.	Orchidaceae
20	*Epipactis gigantea* Douglas	Orchidaceae
21	*Epipactis helleborine* (L.) Crantz	Orchidaceae
22	*Epipactis veratrifolia* Boiss. & Hohen.	Orchidaceae
23	*Gymnadenia orchidis* Lindl.	Orchidaceae
24	*Habenaria aitchisonii* Rchb.f.	Orchidaceae
25	*Habenaria intermedia* D.Don	Orchidaceae
26	*Herminium edgeworthii* (Hook.f. ex Collett) X.H.Jin, Schuit., Raskoti & Lu Q.Huang	Orchidaceae
27	*Herminium lanceum* (Thunb. ex Sw.) Vuijk	Orchidaceae
28	*Herminium latilabre* (Lindl.) X.H.Jin, Schuit., Raskoti & Lu Q.Huang	Orchidaceae
29	*Herminium monorchis* (L.) R.Br.	Orchidaceae
30	*Liparis rostrata* Rchb.f.	Orchidaceae
31	*Malaxis muscifera* (Lindl.) Kuntze	Orchidaceae
32	*Neottia inayatii* (Duthie) Schltr.	Orchidaceae
33	*Oreorchis micrantha* Lindl.	Orchidaceae

Table 3. Floristic composition of plant species with in families Zingiberaceae, Musaceae and canaceae under order Zingiberales

Sr No	Plant Species Name	Families
1	*Elettaria cardamomum* (L.)Maton	Zingiberaceae
2	*Curcuma longa* L.	Zingiberaceae

3	*Roscoea alpina* Royle	Zingiberaceae
4	*Zingiber officinale* Roscoe	Zingiberaceae
5	*Musa paradisiaca* L.	Musaceae
6	*Canna indica* L.	Cannaceae

Table. 4 Plant species classified under the order Dioscoreales

Sr No	Plant Species Name	Family
1	*Dioscorea deltoidea* Wall. ex Griseb.	Dioscoreaceae

Table.5 Species composition of the family Araceae within the order Alismatales

Sr No	Plant Species Name	Families
1	*Alocasia cucullata* (Lour.)G.Don	Araceae
2	*Arisaema flavum* (Forssk.) Schott	Araceae
3	*Arisaema jacquemontii* Blume	Araceae
4	*Colocasia esculenta* (L.)Schott	Araceae
5	*Sauromatum venosum* (Dryand. ex Aiton) Kunth	Araceae

Table.6 Taxonomic diversity of plant species with in order Arecales comprising family Arecaceae

Sr No	Plant Species Name	Families
1	*Phoenix dactylifera* L.	Arecaceae
2	*Trachycarpus fortunei* (Hook).H.Wendl.	Arecaceae

Table.7 Representative Species of the family Commelinaceae under the order Commelinales

Sr No	Plant Species Name	Families
1	*Commelina benghalensis* L.	Commelinaceae
2	*Commelina obliqua* Vahl	Commelinaceae

Table. 8 Diversity of families Colchicaceae, Liliaceae, Melanthiaceae, and Smilacaceae within the order Liliales

Sr No	Plant Species Name	Families
1	*Colchicum luteum* Baker	Colchicaceae
2	*Notholirion thomsonianum* (Royle) Stapf	Liliaceae

3	*Gagea lutea* (L.) Ker Gawl.	Liliaceae
4	*Tulipa clusiana* Redouté	Liliaceae
5	*Paris polyphylla* Sm.	Melanthiaceae
6	Trillium govanianum Wall. ex D.Don	Melanthiaceae
7	*Smilax aspera* L.	Smilacaceae
8	*Smilax elegans* Wall. ex Kunth	Smilacaceae

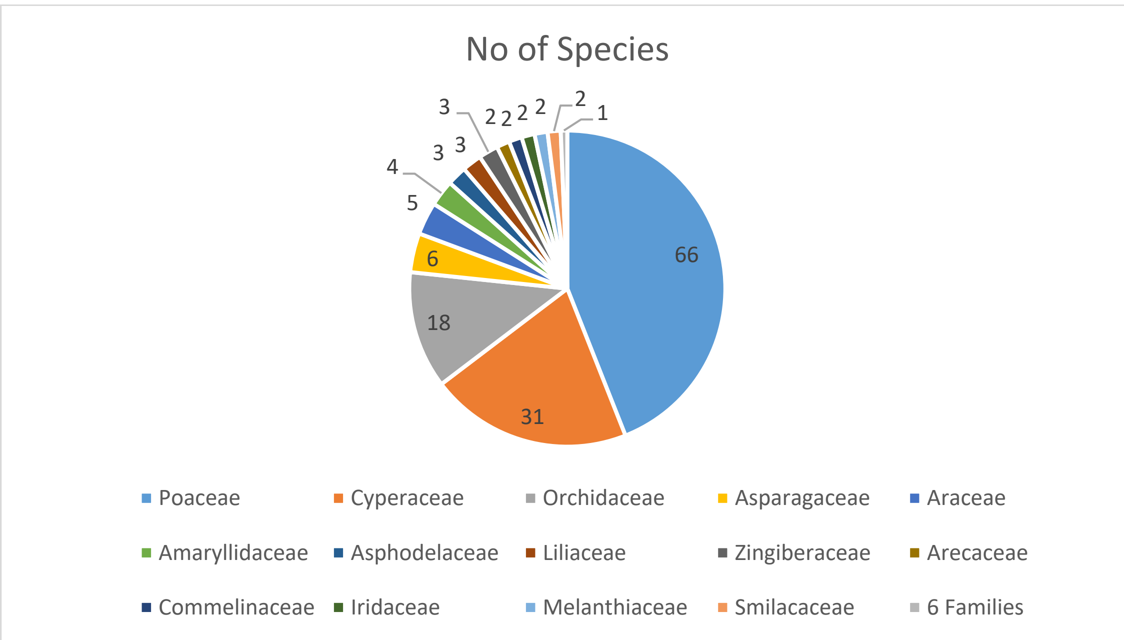

Figure 2. Number of taxa per family based on taxa surveyed in the District Muzaffarabad

Life Form Classification

Based on Raunkiaer's system, four life-form classes were recorded: geophytes (55.48%, 86 species), therophytes (29.03%, 45 species), hemicryptophytes (14.10%, 22 species), and megaphanerophytes (1.92%, 3 species). Geophytes dominated due to the prevalence of rhizomatous and underground stem-bearing plants.

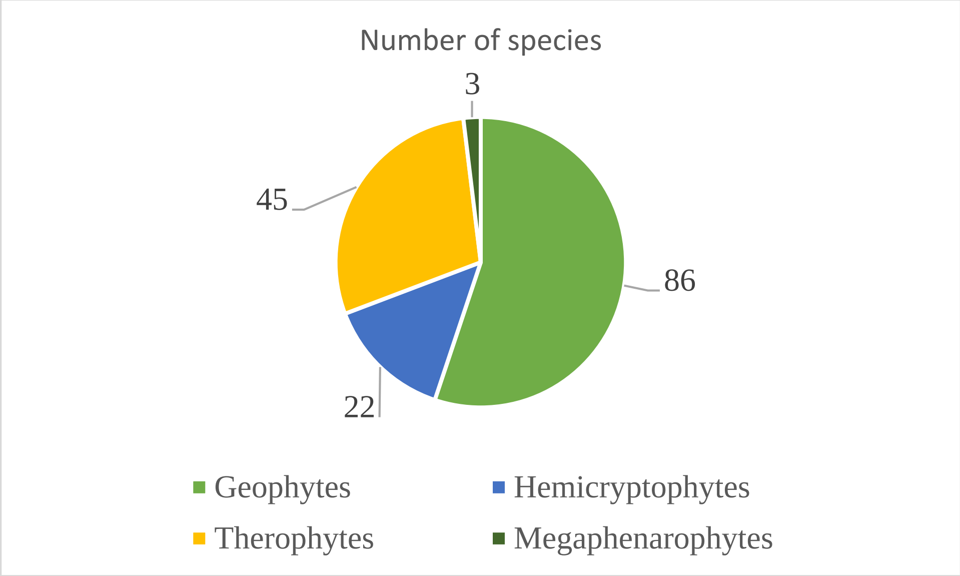

Figure. 3 Different life forms recorded from District Muzaffarabad

Growth Habit

Growth forms were classified as grasses (62.18%, 97 species), herbs (35.90%, 56 species), and trees (1.92%, 3 species). Grasses were predominant and mainly belonged to Poaceae and Cyperaceae. Forbs were found in 17 families, including Orchidaceae, Asparagaceae, and Zingiberaceae.

Microhabitats

Monocot plants were classified into five main habitat types: hydrophytes, mesophytes, agricultural fields, disturbed lands, and xerophytes. Mesophytes were most common (59 species), followed by agricultural fields (28 species), disturbed land (39 species), xerophytes (19 species), and aquatic habitats (16 species). Subcategories such as grasslands, shady areas, dumping sites, road sides, marshes, and rock crevices further reflected the ecological diversity.

Phytogeographical Affinities

Phytogeographic analysis revealed that the majority of species belonged to the Western Himalayan element (25%, 39 species), followed by Eurasian (16.03%, 25 species), Palaeotropical (9.62%, 15 species), Pan-tropical and cosmopolitan (8.97%, 14 species), Central Asian (7.69%, 12 species), Mediterranean and Holarctic (3.21%, 5 species each). Minor elements included African, Neotropical, and Irano-Turanian, each with fewer than five species.

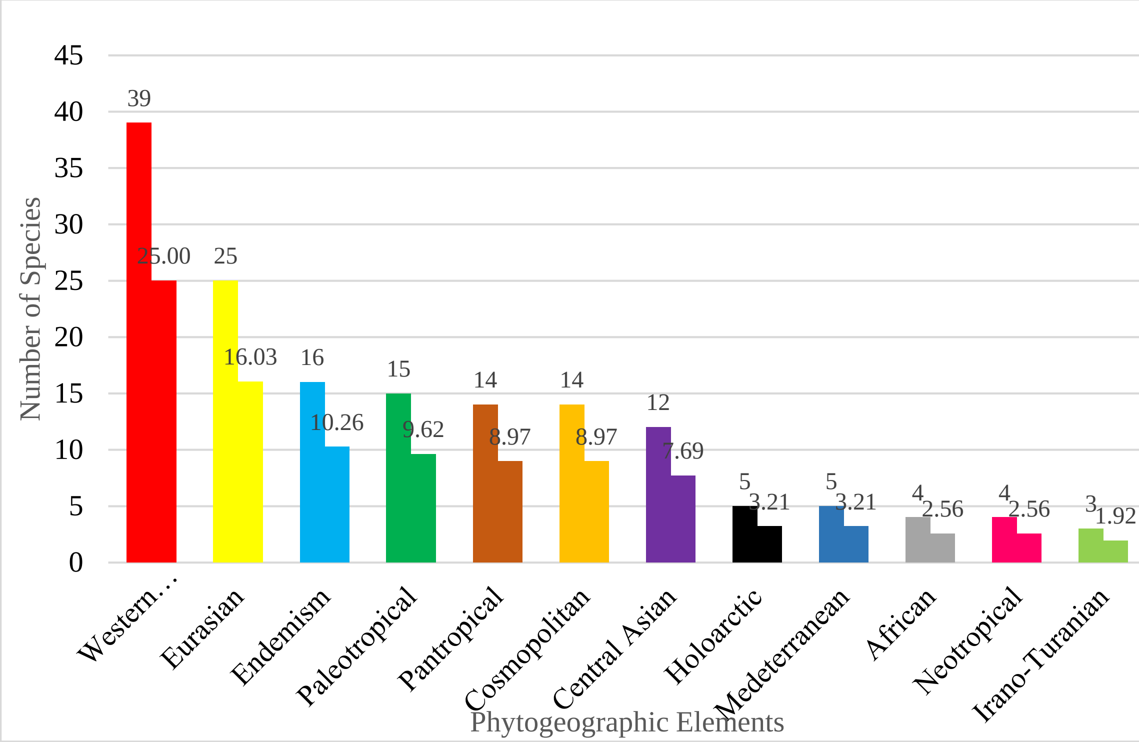

Figure.4 Phytogeographical distribution of monocotyledonous species in District Muzaffarabad, AJK

Endemic Species

Sixteen species were identified as endemic to the Kashmir region, spanning 8 families and 15 genera. Orchidaceae contributed the highest number (5 endemic species), followed by families such as Araceae, Cyperaceae, and Asparagaceae. Notable endemic species included Dienia cylindrostachya, Neottia inayatii, and Paris polyphylla.

Experiment-2: Ferns and Fern-Allies

Floristic Analysis

The present study documented a total of 81 Pteridophytic species from District Muzaffarabad, comprising 80 true ferns and a single fern-ally (*Selaginella chrysocaulos*) belonging to the family Selaginellaceae. These taxa were classified into seven orders, eighteen families, and thirty genera. Among these, the order Polypodiales was dominant, representing 67% of the families. Taxonomic analysis at the family level revealed that five leading families contributed over 56% of the genera, while thirteen families were monogeneric. The most diverse family in terms of species was Dryopteridaceae, comprising 22 species. Pteridaceae followed, represented by seven genera with 18 species, while Thelypteridaceae and Polypodiaceae contributed three and two genera, respectively. Family Aspleniaceae was notable among monogeneric families with seven species under the genus *Asplenium*. Other important families included Blechnaceae and Equisetaceae, each with four species. In terms of genera, *Dryopteris* was the most species-rich (13 spp.), followed by *Asplenium* (7 spp.), *Adiantum* and *Polystichum* (6 spp. each), and *Thelypteris* (5 spp.). Several genera such as *Marsilea*, *Ophioglossum*, and *Woodsia* were monospecific, yet of significant ecological and conservation importance due to their rarity in the region.

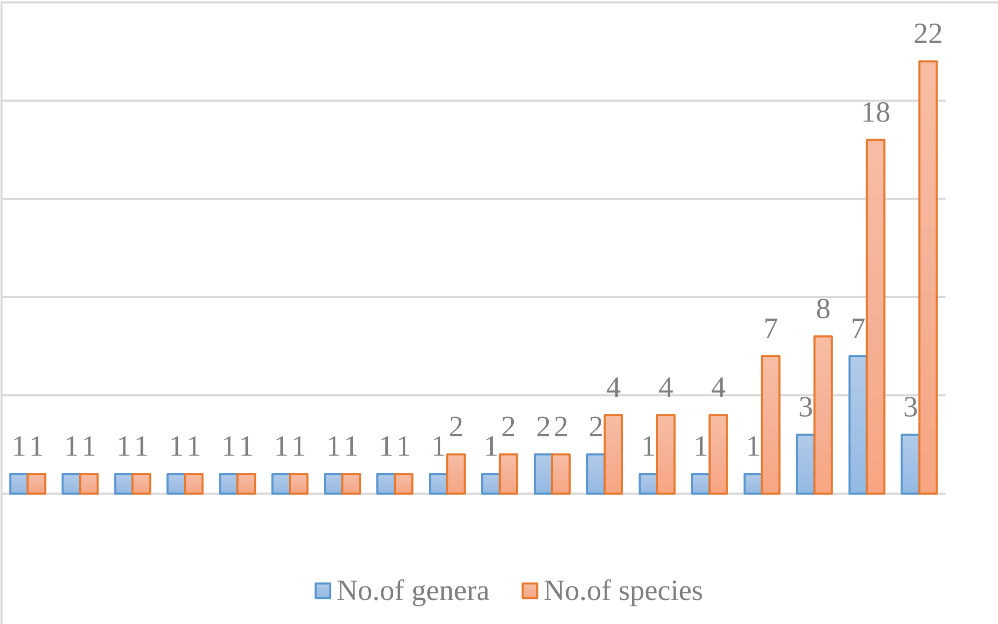

Figure. 5 Distribution of genera and species in different fern families recorded from study area.

Ecological Zonation

The distribution of fern species across ecological zones revealed that the majority (47 spp.) occurred in temperate zones, while 23 species were found in subtropical areas. A few species were observed in transitional habitats spanning from subtropical to alpine zones. The altitudinal range of these species extended from approximately 1200 to 4000 meters above sea level.

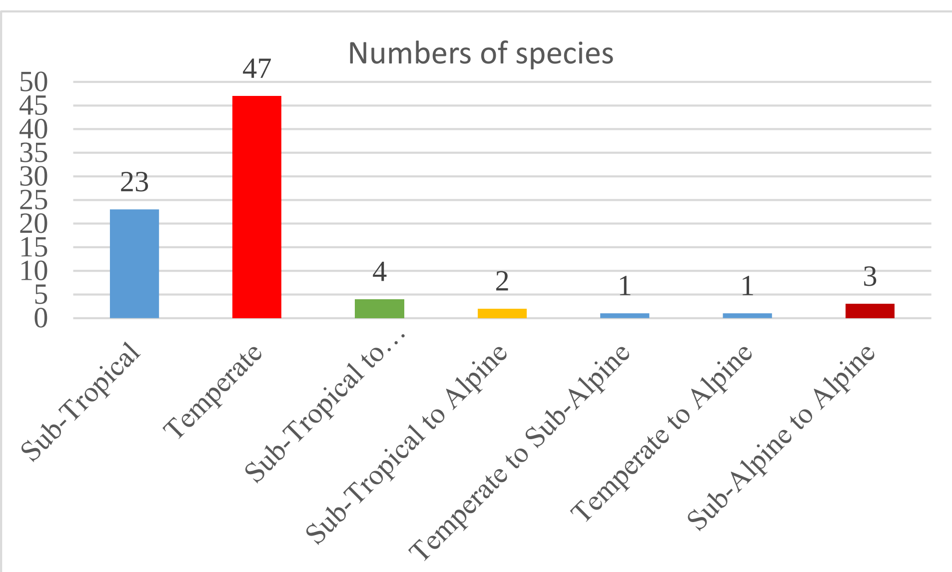

Figure.6 Ecological zonation and altitudinal distribution of fern species in District Muzaffarabad, AJK

Microhabitat Distribution

The microhabitat categorization showed that the highest number of fern species (27 spp.) occurred in the inner core of forests, followed by rock crevices (15 spp.), and disturbed lands (8 spp.). Other microhabitats included dripping water zones, shaded forest edges, epiphytic sites, swamps, alpine meadows, and a few aquatic and barren locations. Overall, 60 species were terrestrial, 17 lithophytic, 3 epiphytic, and 1 aquatic (*Marsilea minuta*).

Ethnobotanical Uses

Ethnobotanical analysis revealed that sixteen fern species were consumed as vegetables, mostly in their juvenile stage when the circinate fronds were tender. Species like *Asplenium trichomanes*, *Diplazium esculentum*, and *Pteridium aquilinum* were among those utilized. One species (*Salvinia natans*) was used for herbal tea preparation. In addition, twenty-nine species were reported for medicinal purposes, used to treat a variety of ailments such as liver disorders, jaundice, respiratory issues, urinary problems, and skin diseases. Different plant parts such as fronds, rhizomes, young leaves, roots, and whole plants were used, often in the form of extracts, powders, or pastes.

Quantitative Ethnobotany

The Relative Frequency of Citation (RFC) values ranged from 0.66 to 0.075. The highest RFC values were recorded for *Equisetum arvense* and *Asplenium ceterach*, indicating these species were the most frequently cited by informants. Use Value (UV) estimates showed *Equisetum arvense* (0.26), *Diplazium esculentum* (0.19), and *Adiantum capillus-veneris* (0.17) as the most widely used species, while *Lygodium microphyllum*, *Cystopteris fragilis*, and *Cheilanthes acrostica* had the lowest UV values (0.025). Relative Importance (RI) analysis revealed that *Adiantum caudatum*, *Asplenium trichomanes*, *Dryopteris cristata*, and *Thelypteris palustris* had the highest RI value of 100, showing their wide therapeutic relevance, while *Equisetum arvense* had the lowest RI value (16.66). Fidelity Level (FL) values indicated that *Equisetum arvense* had the highest preference (82.85%), followed by *Equisetum ramosissimum* (50%). The Informant Consensus Factor (ICF) ranged from 0.81 to 1.00 across 13 disease categories. The highest consensus (ICF = 1) was reported for spleen disorders, with *Asplenium adiantum-nigrum* being the key species used. High ICF values were also reported for urinary disorders, diabetes, leucorrhoea, respiratory problems, and edema, reflecting strong agreement among informants about the medicinal utility of certain species.

Phytogeographical Affinities

Phytogeographical classification revealed that the recorded fern flora belonged to thirteen distinct elements. The Western Himalayan region was the most represented, with 19 species (23.45%), followed by Holarctic (12 spp., 14.81%) and Eurasian elements (10 spp., 12.34%). Other notable contributions included the Eastern Himalayan and Pantropical elements, each contributing eight species (9.87%). Eastern Asiatic, Cosmopolitan, Mediterranean, and Circumboreal elements had moderate representation, while Paleo-tropical, Irano-Turanian, Saharo-Arabian, and Sub-Cosmopolitan elements had very limited representation.

Spatial Distribution

Field surveys conducted from May 2022 to August 2023 revealed that fern and fern-ally richness was unevenly distributed across the 28 union councils of Muzaffarabad. Species richness was highest in Union Council Machiara, with up to 45 species, followed by Bheri-2 and Hattian Dopatta. Moderate species richness was observed in Panjkot, Naseerabad, and Kahori. The least species richness was recorded in urban union councils such as Gojra, Langarpura, and Municipal Corporation Muzaffarabad. The spatial analysis using ArcGIS 10.4 showed that environmental heterogeneity and elevation played a significant role in shaping the distribution pattern of fern diversity across the district.

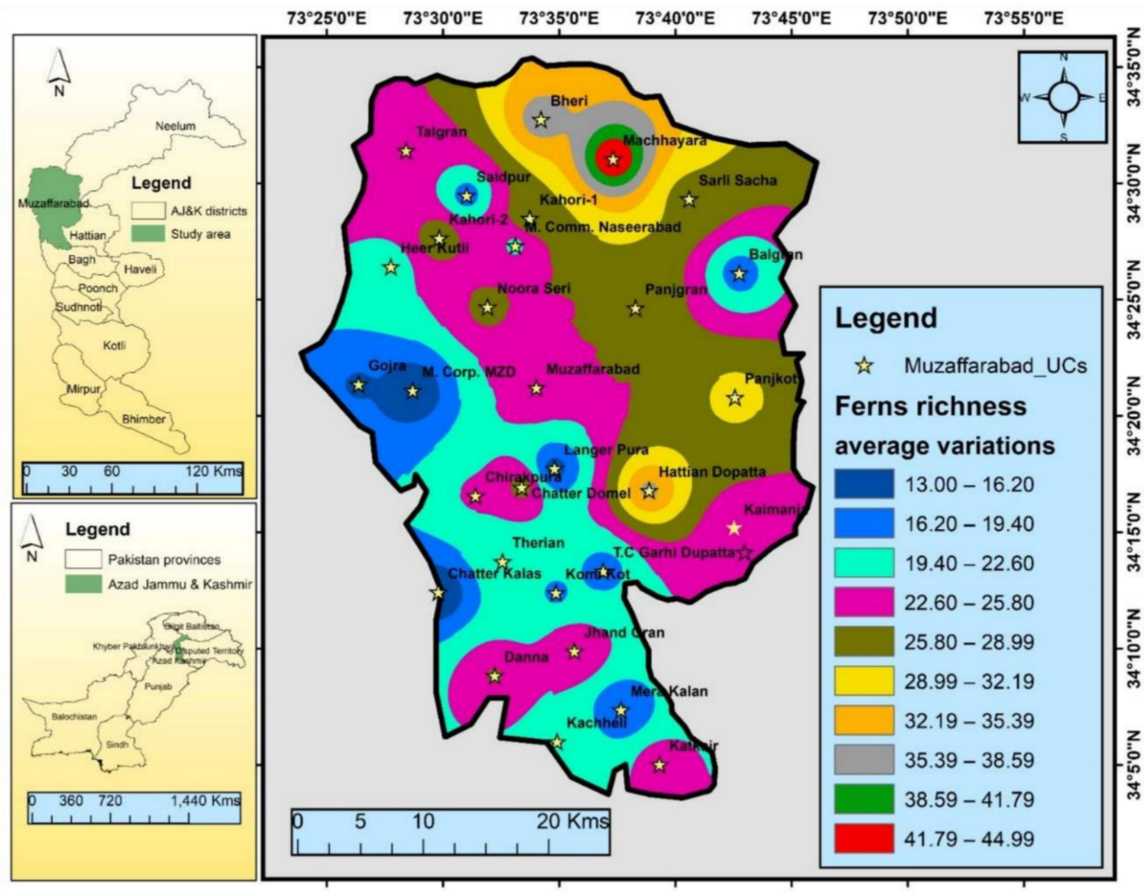

Figure 7. Map of average variation in Fern species richness recorded from District Muzaffarabad

5. Discussion

The present study provides a comprehensive assessment of monocotyledonous plant diversity in District Muzaffarabad, Azad Jammu and Kashmir, highlighting a rich taxonomic composition comprising 156 species distributed across 95 genera and 20 families. This level of diversity is significantly higher than previously reported findings from the region, such as those by Dar et al. [56], Khan et al. [8], and Hussain et al. [45], indicating an expanded understanding of the monocot flora. Notably, Poaceae emerged as the most dominant family, comprising over 66 species, followed by Cyperaceae (31 species), Orchidaceae (18), Asparagaceae (6), and Araceae (5). The dominance of Poaceae aligns with earlier reports from the Western Himalayas and is attributed to their wide ecological amplitude, high seed production, rapid growth, and efficient colonization mechanisms such as rhizomes and stolons.

The life form spectrum revealed a predominance of geophytes (85 species), followed by therophytes (45), hemicryptophytes (22), and mega phanerophytes (3), suggesting strong adaptation to the temperate mountainous environment. The prevalence of geophytes reflects plant strategies to endure adverse climatic conditions, particularly in areas with seasonal drought or fire events. The limited representation of woody monocots (only 3 species) supports the general trend of herbaceous dominance in monocot groups due to evolutionary constraints and ecological factors.

Phytogeographical analysis categorized the recorded species into 12 distinct elements, with the Western Himalayan region contributing the highest proportion (25%), followed by Eurasian (16.03%), Palaeotropical (9.62%), Pan-tropical and Cosmopolitan (8.97%), and Central Asian (7.69%) elements. These findings are consistent with previous studies [57,18] and reflect the biogeographic affinities of the flora with adjacent Himalayan and temperate regions. The dominance of Western Himalayan elements is likely influenced by historical geological events, climatic variability, and dispersal mechanisms that have facilitated species migration and diversification.

The presence of 16 endemic species, primarily from Orchidaceae, Cyperaceae, and Araceae, underscores the conservation significance of the area. Although lower than broader-scale studies such as Dhar and Kachroo [58], the number of endemics found within the limited geographical scope of this study reflects the region's unique microhabitats and ecological niches. These endemic taxa highlight the need for habitat-specific conservation efforts to protect the region's botanical heritage. Overall, this study contributes valuable insights into the floristic diversity, ecological strategies, and phytogeographic relationships of monocotyledonous flora in a relatively underexplored Himalayan region. The restricted distribution of these taxa supports ecological theories that suggest species with narrow geographic ranges are often associated with areas of low seasonal variability and habitat stability [59]. Conversely, species with broader thermal tolerances tend to occupy wider elevational and climatic gradients. The concentration of endemic species in Muzaffarabad heterogeneous landscape, influenced by complex topography and varied microclimates, underscores the region's role as a potential refugium and highlights its conservation value. The findings can inform future biodiversity assessments, conservation planning, and sustainable management practices in Azad Jammu and Kashmir.

District Muzaffarabad, located within the Irano-Turanian phytogeographic region of Pakistan, has remained underexplored in terms of fern diversity due to its challenging topography and restricted access owing to its proximity to the Indian border. Despite these constraints, the current investigation successfully documented 81 taxa of ferns and fern-allies, belonging to 30 genera and 18 families. These findings align closely with prior studies such as those of [61], and [62], indicating consistency in fern diversity patterns across the Kashmir region. Among the recorded families, Dryopteridaceae emerged as the most dominant, comprising 22 species, while Dryopteris was identified as the leading genus with 13 species, consistent with the floristic compositions reported by [63,64], [65], and [62]. The high diversity of ferns in the Kashmir region can be attributed to its moderate climate, humid conditions, forest density, and water availability, particularly within an altitudinal range of 800–3000 meters, which offers an ideal ecological niche for fern proliferation.

Ferns are ecologically significant due to their unique adaptations and limited utility compared to higher plants. They often colonize steep slopes, exposed rocks, decaying logs, and nutrient-poor soils where other vascular plants may not thrive. Their fibrous root systems contribute to soil stabilization and erosion control. Furthermore, specific fern taxa act as bioindicators of microclimatic conditions: species such as Dryopteris sparsa, Adiantum venustum, and Asplenium adiantum-nigrum indicate cool, moist habitats, while the presence of Adiantum capillus-veneris and Thelypteris dentata suggests year-round water seepage. Some species (Pteris cretica, Adiantum caudatum) prefer disturbed or degraded habitats, further highlighting their ecological significance.

Despite their low medicinal utility compared to higher plants, ferns hold an important place in forest ecosystems and traditional ethnobotanical practices. Local communities use young fronds, dried rhizomes, and decoctions of various species for ailment treatment, suggesting potential value for phytochemical and pharmacological research. However, many fern species in the region are threatened due to narrow habitat specificity, limited population size, and human-induced pressures such as deforestation, construction, and climate change. These pressures result in significant habitat alteration and species range shifts. The absence of conservation status assessments under IUCN guidelines for Pakistani ferns is a major concern. Immediate attention is needed to evaluate the conservation priorities, especially in biodiversity-rich and ecologically sensitive areas such as Saran, Pir Chinasi, and Kutla, which may harbor rare or endemic taxa. The study further underscores the importance of species distribution modelling (SDM) using GIS tools such as ArcGIS 10.4, which, when combined with accurate georeferenced herbarium records and climatic data (temperature, rainfall), can enhance our understanding of species ranges. Such models serve as valuable tools in conservation planning, filling data gaps, and guiding field surveys to prioritize rare and endangered taxa.

Conclusion

This study provides a detailed assessment of monocotyledonous and pteridophytic plant diversity, highlighting their ecological distribution and conservation significance. A total of 156 monocot species from 95 genera and 20 families, and 81 fern and fern-allied species from 30 genera and 18 families were recorded. Poaceae and Dryopteridaceae were the dominant families within the monocots and ferns, respectively. Life-form analysis revealed a predominance of geophytes among monocots, while ferns were more abundant in terrestrial and lithophytic habitats. Phytogeographical analysis showed strong affinities with the Western Himalayan region for both groups, with notable endemism, particularly among monocots. These findings underscore the rich yet underexplored floristic diversity of the region, emphasizing the critical need for vigilant, habitat-specific conservation strategies. Given the escalating threats from anthropogenic pressures, climate change, and habitat degradation, this research stresses the need for continuous, proactive conservation efforts to protect the unique plant diversity of this ecologically sensitive Himalayan landscape.

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