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RESEARCH ARTICLE

Phytosociology and species diversity analysis of district Swabi, Khyber Pakhtunkhwa, Pakistan: An approach for forest conservation

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Abstract

Plant diversity is a key component of an ecologically stable environment and plays a crucial role in regulating nutrient cycling, energy flow and overall resilience of ecosystems. This study assessed the plant diversity across 4 tehsils (Lahor, Razzar, Swabi and Topi) in district Swabi, Khyber Pakhtunkhwa, Pakistan. The objective of the study was to examine the interaction between plant communities and ecological dynamics. Also documented the plant diversity of district Swabi, identifying 173 plant species belonging to 61 families. Angiosperms were the most dominant group with 168 species, followed by pteridophytes (3 species) and gymnosperms (2 species). Diverse habitat preferences were observed, with mesic habitats hosting 57.2 % of the species. Herbaceous species were the most abundant (25.4 %), followed by shrubs (25.4 %) and trees (17.3 %). Phenological assessment showed a variety of life cycles, with perennials making up 32.3 % of the species. Albeit, identified threats such as overgrazing (23.6 %) and habitat fragmentation impacted 74 % of the species. Chorotype analysis categorized species into uni-regional (31.2 %), bi-regional (42.7 %) and pluri-regional (20.2 %) distributions, with 8.67 % exhibiting cosmopolitan characteristics. The species abundance heatmap revealed Tehsil-Topi exhibited the highest alpha diversity, while Tehsil-Lahor showed the lowest. Additionally, Bray-Curtis Dissimilarity Heatmap highlights key ecological relationships among plant species. The analysis suggests that Topi is a diverse ecological hotspot, contributing significantly to overall biodiversity in the region. Principal Component Analysis (PCA) further indicates that geographical and anthropogenic influences shape plant diversity patterns. These findings underscore the need for targeted conservation strategies to protect Swabi unique biodiversity.

Keywords: abundance; chorotype; community ordinations; floristic composition; phenology; season; threats

Introduction

Plant diversity is one of the complex units that help sustain life on this planet. They operate at multitude of interacting spatial and temporal scales which shape the system and impact on the dynamics of individual populations. The disturbance in the dynamic interaction of both biotic and abiotic components of the environment also structures an ecosystem. Among the biotic communities, plant diversity is a crucial component of a healthy and ecologically sound ecosystem (1). Plant diversity is considered a prerequisite to maintaining ecosystem dynamics (2). Diversity in plant communities promotes numerous ecosystem services like mediating climate change, maintaining a smooth flow of biogeochemical cycles, providing habitat to a vast range of organisms, preventing soil erosion and improving the quality of life for all organisms (3–6). The distribution of plant diversity in an area reflects the gradient of energy and the limiting resources (7). It also assists in elucidating the effectiveness of the gradient to facilitate the functioning of ecosystems. Decline in the plant diversity of a region has serious consequences for ecosystem stability, while high plant diversity supports diverse and consumer communities (8). The knowledge of the floristic composition is important to understanding the ecosystems of an area as well as possible anthropogenic impacts on the regional vegetation in the near future (9).

The northern and northwestern regions of Pakistan are home to diverse plant communities due to friendly climatic conditions (10). District Swabi is approximately 321 m above sea level with semi-arid and subtropical weather conditions. Due to its unique location in the monsoon and western disturbances, it experiences heavy rainfall and has high humid in the air all year round. During the months of June and July, its mean maximum temperature rises to 40 - 42 °C (11). On the other hand, December and January are the coolest months of the year with temperature reaching approximately 2 °C. The monsoon season is associated with heavy rainfall in KPK and most of the rainfall occurs in the month July and August. The hilly areas with high altitudes also receive snowfall in the winters apart from heavy rainfall in summers. District Swabi consists of 4 tehsils namely Swabi, Lahor, Topi and Razar. The favorable weather pattern, elevation, rainfall and humidity makes it an ideal spot for plant diversity to thrive (12).

The richness of plant diversity in the district of Swabi and nearby regions in KPK province has been studied over the years. The focus of the researchers was ethno-botanical studies to explore more plants over the year for their use in traditional medicines. The reported 32 species belonging to 23 families from wetlands of district Swabi (13). However, the reported 63 medicinal plant species belonging to 36 families from the Karamar valley of district Swabi (14). In addition to that, the reported 221 medicinal plants belonging to 105 families from the areas of district Swabi and Hazara (15). Furthermore, a study conducted a detailed quantitative ethnomedicinal study on the flora of district Swabi and reported that 130 genera distributed in 58 families are used in different types of treatment by locals (16). Recently, a study carried out floristic and vegetation diversity studies in Gadoon Hills, Outer Himalayas, district Swabi (12). The result revealed by the floristic composition by confirms the presence 107 plant species of 98 genera and 54 families in the Gadoon Hills. Moreover, the reports further explained that the flora of Swabi has been massively affected by major threats like nutrient deficiency, overgrazing, soil erosion and overexploitation (12). Due to these threats, shrubs and trees in Gadoon Hills are far away from each other and have stunted growth. The need of the hour is to maximize the conservation efforts to prevent the loss of economically and ethno-medicinally important plant species.

Due to the immense ethnomedicinal potential of plants in district Swabi, researchers have been giving special attention to explore more plant diversity. Most of the studies on the assessment of plant diversity conducted in district Swabi are on a single area or just the ethnomedicinal perspective. There is a clear research gap to thoroughly explore the flora and vegetation of all the 4 tehsils of district Swabi. There is an urgent need to study the plant diversity of district Swabi to determine the role of plants in ecosystem dynamics and make conservation efforts to protect the flora. In recent years, some of the threats have negatively affected the plant diversity and disturbed the natural balance of the region. To fill this gap, this study assessed the plant diversity of all 4 tehsils in the district Swabi. The phytogeography of the area was examined to document the vegetation of district Swabi, Khyber Pakhtunkhwa, Pakistan. Particularly, with a focus on floristic composition, ecological features, chorotype analysis and a phenology-based approach to flora. The biological spectrum of the study sites was analyzed to provide a clear image of the region climates, phenological patterns and vegetation distribution across the tehsils.

The environmental factors in correlation with the biotic and abiotic factors are also reflected in the chorotype analysis. The data gathered from this study on plant species diversity and ecosystem functions will be helpful for the region-specific conservation strategies with sustainable use of the plant resources and ecosystems of district Swabi.

The objectives of this study are: To provide a comprehensive assessment of the plant diversity of district Swabi, Pakistan. To explores the ecological dynamics through the aspects of floristic composition, ecological features, chorotype analysis and including a phenology-based approach on the flora To providing a detailed floristic data to develop strategies for conservation of economically important, endangered and vulnerable plant species in the future.

Materials and Methods

Study site

The study was conducted in Swabi, Khyber Pakhtunkhwa, Pakistan. The geographical coordinates were Latitude: 34.04538 North 34°2' 43.356"and Longitude: 72.32212 East 72° 19'19.65". The study area is often affected by the monsoon, western disturbances, increasing humidity and rainfall. In winter, the temperatures range from 4 to 10 ºC and December is the coolest month of the year in the district Swabi. Most of the rains occur during the monsoon in year. Their summer temperatures increase to 37 - 42 ºC and temperatures are very hot (Fig. 1).

Field survey

The whole study area, including mountains, graveyards and stream banks, was thoroughly explored in different seasons of the year during 2021-2022. Different ecosystems were visited and plants were collected. The plants were photographed, brought to the university herbarium and identified with the help of taxonomists. Preserved specimens from each location were deposited and allotted specimen numbers. Other ecological characteristics of plants like habit form, spines, seasons and abundance were carefully determined during the study. The nomenclature is based on The World Flora Online (http://www.worldfloraonline.org/).

Data Collection

Data collection was conducted using a stratified random sampling method, with 50 sites selected to represent diverse vegetation. Each site consisted of a 10 m × 10 m plot, covering 100 m^2 following the method of (17). At each site, wild plant species were recorded, noting abundance, plant habit, leaf morphology, spines, flowering seasons and other ecological characteristics. Environmental factors, such as elevation were documented. Collected specimens were pressed, dried and identified with the help of taxonomists, then stored in the university herbarium. Species identification was verified through The World Flora Online database. Data from each plot were replicated 3 times to ensure robust analysis of species diversity and distribution.

Floristic composition

The floristic was based on the Raunkiaer life form spectrum and all wild plant species were randomly collected in the area and their botanical name, family name, habitat, life from, leaves size while abundance of species, leaf types, spines, flowering seasons, etc. were documented (18).

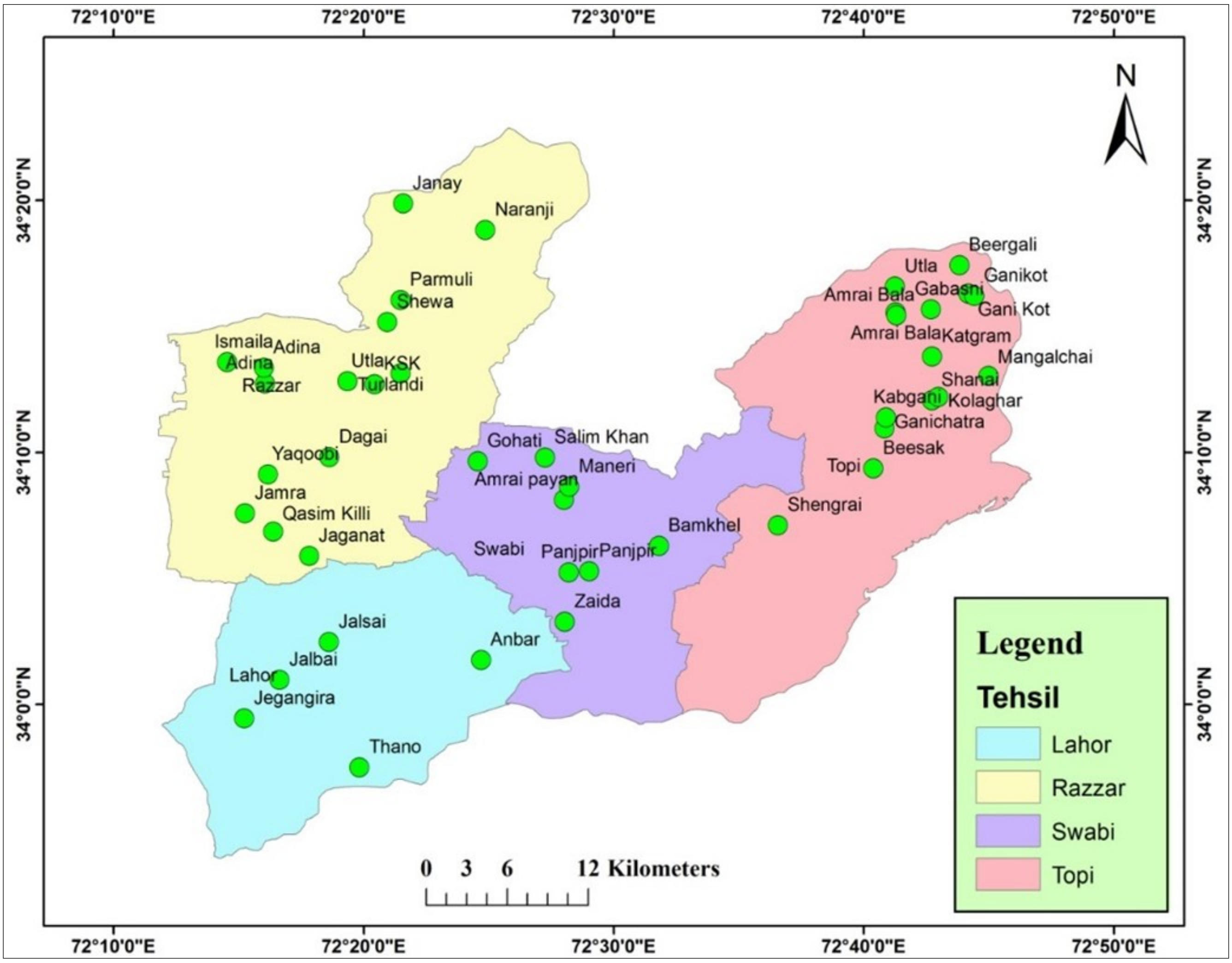

Fig. 1. Map of district Swabi showing the precise locations of plant collection sites, emphasizing the diverse ecological habitats surveyed for the study of plant diversity and ecological patterns.

Life form spectrum

The Raunkiaer life form spectrum classification was used for classification of species into various life forms (19). The followed data were represented according to below equation and rules.

$$\text{Raunkiaer Biological spectrum} = \frac{\text{No. of individual of a species of a particular life form}}{\text{No of total of all species in a single strande}} \times 100 \quad \text{(Eqn .1)}$$

Leaf form spectrum

Leaf morphology provides crucial insights into the flora of an area, aiding in species classification and ecological understanding. Following Raunkiaer's classification, plants are categorized based on leaf size into several classes (19). The leaf form spectrum includes leptophyllous plants, with leaf sizes up to 25 mm^2; nanophyllous plants, up to 25 × 9 mm^2; microphyllous plants, up to 225 × 9 mm^2; mesophyllous plants, up to 2025 × 9 mm^2; macrophyllous plants, up to 18225 × 9 mm^2 and megaphyllous plants, up to 164025 × 9 mm^2. Analyzing the composition of these leaf forms provides foundational data for understanding plant adaptations and ecosystem dynamics within the study area.

Sociability

For examining the relation and closeness between the species in an area is entitled as sociability using:

$$\text{Sociability} = \frac{D \times 100}{f} \quad \text{(Eqn .2)}$$

Where the "D" is the density of a species, "f" is the frequency of a species. Based on this formula, the sociability was divided into 5 categories (Table 1).

Chorotype analysis

The chorotype analysis was conducted using, categorizing species into 3 major chorological categories Such as Irano-Turanian species exhibit distribution primarily in central Asian countries, with their diversity centering in western areas (20). Sino-Japanese species are found predominantly in the northern part of the study region. Mediterranean species are distributed across southern Europe, North Africa and western Asia. This analysis provides insights into the geographical distribution patterns of plant species within the study area, contributing to our understanding of regional plant biogeography and ecological associations (Table 2).

Diversity Indices

Alpha Diversity

Measured with the Shannon Diversity Index (21).

Table 1. The categories of sociability according to given formula

S1	These individuals are found singly.
S2	These individuals are found in small groups.
S3	These individuals are found in small patches.
S4	These individuals are found in large patches.
S5	These individuals are found in aggregated form in population.

$$H^1 = -\sum_{i=1}^{S} pi\ In\ (pi) \qquad \text{(Eqn. 3)}$$

Where *H′* is the Shannon Diversity Index, *S* is the total number of species and p_i is the proportion of the species.

Beta Diversity

Calculated by the Bray-Curtis dissimilarity index (22).

$$BC = \frac{2C}{a+b} \qquad \text{(Eqn. 4)}$$

Where BC is the Bray-Curtis dissimilarity index, a and b are the total number of species in 2 different communities and c is the number of species common to both communities.

Gamma Diversity

Indicates total species richness across all Tehsils.

These metrics are essential for understanding species diversity within and between ecological communities.

Species Accumulation Curve (SAC)

Species richness was assessed using a species accumulation curve (SAC) (23), which plots the cumulative number of species against the number of sampled sites. The curve helps visualize how species richness increases by adding more sampled sites. The formula for SAC is

$$S\,(\mathrm{n}) = -\sum_{i=1}^{n} si \qquad \text{(Eqn. 5)}$$

where *S(n)* is the species richness at *n* sites and *Si* is the species richness at the i^{th} site.

Principal Component Analysis (PCA)

PCA was used to explore patterns in species composition and abundance across sampled sites. It transforms standardized abundance data to identify dominant gradients in species distribution. The analysis decomposes the data into site scores *T*, species loadings *P′* and a residual matrix *E* represented by the formula:

$$X = T \cdot P' + E \qquad \text{(Eqn. 6)}$$

This method helps visualize and interpret how species diversity variations exist in the community, providing insights into ecological patterns and each species diversity across the study area.

Results

Plant data composition

In this study, we documented 173 species belonging to 61 families. Among these 3 species were Pteridophytes (2 species in Pteridaceae, 1 species in Equisetaceae). Gymnosperms included 2 species (one each in Cupressaceae and Cycadaceae). The largest division were Angiosperm with 168 species. Twenty-one species were Poaceae, while the second largest family was Fabaceae (14 species), followed by Asteraceae (11 species). Amaranthaceae and Brassicaceae had 9 species each, Solanaceae 8 species and Malvaceae 7 species. The families Euphorbiaceae, Lamiaceae and Moraceae contained 6 species each; Apiaceae and Papaveraceae 4 species; Apocynaceae, Boraginaceae, Cucurbitaceae, Polygonaceae 3 species each; Amaryllidaceae, Convolvulaceae, Caryophyllaceae, Myrtaceae, Nyctaginaceae, Plantaginaceae, Rhamnaceae, Rutaceae, Verbenaceae and Zygophylaceae 2 species each. In the remining families Asparagaceae, Aizoaceae, Acanthaceae, Berberidaceae, Canabaceae, Cyperaceae, Cannabaceae, Cactaceae, Datiaceae, Ebenaceae, Juglandaceae, Lythraceae, Menispermaceae, Nitrariaceae, Oxaliaceae, Oleaceae, Phyllanthaceae, Pedaliaceae, Portulacaceae, Primulaceae, Ranunculaceae, Rosaceae, Rubiaceae, Sapindaceae, Simaroubaceae, Scrophulariaceae, Salicaceae, Tamaricaceae, Violaceae, Vitaceae and Xanthorrhoeaceae) had one species each (Table 3).

Table 2. Chorological analysis of plant species

Uni-regional	Number of species	Percentage (%)
IT:	23	13.20 %
SJ:	22	12.30 %
MED:	4	2.31 %
Total	**54**	**31.20 %**
Bi-regional		
IT, MED:	13	7.51 %
IT, SJ:	34	19.60 %
IT, SS:	8	4.60 %
MED, SJ:	13	7.51 %
MED, SS	3	1.70 %
SJ, SS:	3	1.70 %
Total	**74**	**42.70 %**
Pluri-regional		
IT, MED, SJ:	4	2.31 %
IT, MED, SS	2	1.15 %
MED, SJ, SS	1	0.57 %
IT, SJ, SS	28	16.10 %
Total	**35**	**20.20 %**
Cosmopolitan	**15**	**8.67 %**
Total	**173**	

Habit and habitat

The flora of area consisted mainly of herbs (99 species, 25.4 %) and the second leading habit was shrubs (44 species, 25.4 %) and trees (30 species, 17.3 %), although trees were rarely observed in the study area. The growth of species depends on the favorable habitat and suitable environmental factors such as water availability, nutritive soil, sunlight, etc. During the exploration most of the species were collected from the mesic habitat (99 species, 57.2 %) while 59 species (34.1 %) were growing in dry habitat. Fifteen species (8.6 %) were observed in moist habitat.

Phenology

The phenology assessment was conducted for of each species. In the study area 56 plant species (32.3 %) were perennials. Of the remaining 117 species, 41 species (23.6 %) were growing in spring and summer (SP, SM), while 30 species (17.3 %) were found in autumn, spring and in summer (A, SP, SM), 15 species (8.6 %) were growing well in winter, spring and summer (W, SP, SM), 9 species (5.2 %) in autumn and winter (A, W), 6 species (3.4 %) were in winter and spring (W, SP), 6 species (3.4 %) in autumn, winter and spring (A, W, SP), 5 species (2.8 %) were growing only in spring (SP), 3 species (1.7 %) in autumn and summer (A, SM), 2 species (1.1 %) had a short life cycle and were found in summer only (SM)

Table 3. Species, life form, phenology, abundance, sociability, leaf size and chorotype analysis of district Swabi, Khyber Pakhtunkhwa, Pakistan

Division/Families/ Species name	Habitat	Seasonal A	W	SP	SM	Habit	Spines	Abundance	Sociability	Leaf type	Leaf persistence	Cultivation status	Life Form	Leaf size	Threats	Chorotypes
Pteridophytes																
Pteridaceae																
Adiantum capillus-veneris L.	Dr	+	+	+	+	H	_	R	S2	Simple	E	W	Hemi	Nano	OG	IT, SJ
Adiantum incisum Forssk.	Dr	+	+	+	+	H	+	R	S1	Simple	E	W	Hemi	Nano	FL	IT, SJ
Equisetaceae																
Equisetum ramosissimum Desf.	Mo	+	+	+	+	H	_	Co	S3	Leafless	E	W	Cham	Leafless	FL	IT, SJ
Gymnosperms																
Cupressaceae																
Cupressus sempervirens L.	Mo	+	+	+	+	T	_	R	S2	Scaly	E	W	MesoP	Lep	FL	IT, SJ
Cycadaceae																
Cycas revoluta Thunb.	Dr	+	+	+	+	S	_	R	S1	Scaly	E	W	Hemi	Nano	FL	SJ
Angiosperms																
Amaranthaceae																
Achyranthes aspera L.	Me	-	-	+	+	H	+	Co	S4	Simple	D	W	Ther	Nano	DF	COS
Amaranthus graecizans L.	Dr	-	-	+	+	H	_	Co	S4	Compound	D	W	Cham	Micro	NT	IT, SS, SJ
Amaranthus spinosus L.	Me	-	-	-	+	H	_	Co	S4	Compound	D	W	Ther	Nano	DF	IT, SJ, SS
Amaranthus viridis L.	Dr	-	-	-	+	H	_	Co	S5	Compound	D	W	Ther	Nano	DF	COS
Aerva javanica (Burm. f.) Juss	Dr	-	-	+	+	H	_	R	S1	Compound	D	W	Hemi	Nano	OG	SJ, MED
Atriplex patula L.	Mo	-	+	+	+	H	_	R	S1	Compound	D	W	Cham	Nano	NT	SJ, MED
Chenopodium album L.	Dr	-	-	+	-	H	_	Co	S4	Compound	D	W	Ther	Micro	DF	IT, SJ
Celosia argentia L.	Me	-	+	+	+	S	+	R	S3	Compound	D	W	Mesop	Macro	DF	SJ, MED
Digera muricata (L.) Mart..	Me	-	+	+	-	H	_	Co	S2	Compound	D	W	Ther	Micro	DF	IT, SJ
Asteraceae																
Artemisia maritima L.	Dr	+	-	+	+	H	_	R	S3	Simple	D	W	Hemi	Lep	DF	IT
Artemisia scoparia Waldst. & Kitam.	Me	+	+	+	+	S	_	R	S3	Compound	E	W	Cham	Lep	DF	IT, SJ
Artemisia scopiformis Ledeb.	Dr	-	+	+	+	S	_	R	S4	Simple	D	W	Hemi	Lep	DF	IT, SJ, SS
Calendula arvensis M.Bieb.	Me	+	+	+	-	H	_	R	S3	Compound	D	W	Ther	Lep	MU	IT
Carthamus oxyacantha M.Bieb.	Dr	+	+	+	-	S	+	Co	S5	Compound	D	W	Ther	Lep	MU	COS
Cirsium arvense (L.) Scop.	Me	+	+	+	+	H	+	Co	S3	Compound	E	W	Hemi	Micro	MU	SJ
Eclipta prostrata (L.) L.	Me	+	+	+	+	H	_	Co	S2	Simple	E	W	Hemi	Micro	MU	MED, SS
Erigeron bonariensis L.	Me	+	-	+	+	H	_	Co	S5	Compound	D	W	Cham	Micro	NT	IT, SJ
Erigeron canadensis L.	Mo	+	-	+	+	S	_	Co	S5	Compound	D	W	Cham	Nano	MU	IT
Sonchus asper (L.) Hill	Me	-	-	+	_	H	_	Co	S4	Compound	D	W	Ther	Micro	FU	SJ
Xanthium strumarium L.	Me	+	-	+	+	S	+	Co	S5	Compound	D	W	Cham	Macro	RE	IT, SJ, SS
Amaryllidaceae																
Allium jacquemontii Kunth.	Me	-	-	+	+	H	_	R	S2	Simple	AP	W	Hemi	Lep	OG	IT, SS
Allium sativum L.	Me	-	-	+	+	H	_	Co	S5	Simple	D	C	Geo	Lep	OG	IT, SS
Asparagaceae																
Agave americana L.	Me	+	+	+	+	S	+	R	S3	Simple	E	W	Cham	Micro	OG	MED, SJ
Apiaceae																
Ammi visnaga (L.) Lam..	Me	-	-	+	+	H	_	Co	S4	Simple	D	C	Ther	Lep	FL	IT, SJ
Anethum graveolense L.	Me	-	-	+	+	S	_	Co	S3	Simple	D	W	Nanop	Lep	NT	IT, MED, SJ
Coriandrum sativum L.	Me	-	+	+	-	H	_	Co	S5	Compound	D	C	Ther	Nano	NT	IT, MED, SJ
Foeniculum vulgare Mill.	Me	-	-	+	+	S	_	Co	S5	Feathery	D	W	Hemi	Lep	NT	COS

Apocynaceae															
Calotropis procera (Aiton) Dryand.	Dr	+	+	+	+	S	_	R	S1	Compound	E	W	Hemi	Micro	FL	IT, SJ, SS
Catharanthus roseus (L.) G. Don	Me	+	+	+	+	H	_	R	S1	Simple	E	W	Cham	Nano	OG	MED
Tylophora hirsuta Wight	Me	+	+	-	-	S	_	R	S1	Simple	D	W	Hemi	Meso	OG	IT, SJ, SS
Aizoaceae																
Trianthema portulacastrum L.	Me	+	-	+	+	H	_	R	S2	Simple	D	W	Ther	Nano	OG	SJ
Acanthaceae																
Justicia adhatoda L.	Me	+	+	+	+	S	_	R	S3	Compound	E	W	NanoP	Mega	OG	IT
Brassicaceae																
Brassica campestris L.	Me	+	+	+	_	H	_	Co	S3	Compound	D	W	Ther	Micro	OG	IT, SJ
Brassica nigra (L.) K. Koch	Me	+	-	+	+	S	_	Co	S4	compound	D	W	Cham	Nano	OG	MED, SJ
Brassica tournefortii Gouan.	Me	-	+	+	+	S	_	R	S2	Compound	D	W	Geo	Nano	FL	IT, SJ
Capsella bursa-pastoris (L.) Medik.	Me	-	-	+	+	H	_	Co	S2	Compound	D	W	Ther	Nano	FL	COS
Lepidium didymum L.	Mo	-	-	+	+	H	_	Co	S4	Simple	D	W	Ther	Lep	FL	MED
Lepidium sativum L.	Dr	-	+	+	+	H	_	Co	S5	Simple	D	W	Ther	Micro	NT	SS, MED
Nasturtium officinale R.Br.	Me	+	+	+	+	H	_	Co	S2	Simple	E	W	Geo	Nano	FL	IT, MED, SS
Noccaea angustifolia F.K. Mey.	Dr	+	+	+	+	H	_	Co	S5	Simple	E	W	Hemi	Micro	NT	SJ, SS
Sisymbrium irio L.	Dr	-	-	+	-	H	_	Co	S4	Simple	D	W	Ther	Nano	OG	COS
Berberidaceae																
Berberis lycium Royle.	Me	-	-	+	+	S	+	R	S3	Compound	D	C	Mesop	Micro	OG	IT, SJ, SS
Boraginaceae																
Cordia dichotoma G.Forst.	Me	-	+	+	+	T	_	Co	S1	Compound	D	W	Megap	Mega	MU	IT, SJ, SS
Cordia myxa L.	Dr	-	-	+	+	T	_	Co	S1	Compound	D	W	MesoP	Macro	MU	IT
Heliotropium idicum L.	Me	+	+	+	+	S	_	R	S3	Compound	E	W	Hemi	Lep	MU	IT
Cucurbitaceae																
Citrullus colocynthis (L.) Schrad.	Me	-	-	+	+	H	_	Co	S5	Compound	D	C	Ther	Micro	NT	IT, SJ
Luffa cylindrica (L.) M. Roem.	Dr	-	-	+	+	H	_	Co	S5	Compound	D	W	Hemi	Nano	NT	IT, SS
Momordica balsamina L.	Me	-	-	+	+	H	_	Co	S3	Compound	D	C	Hemi	Micro	MU	COS
Canabaceae																
Cannabis sativa L.	Dr	+	-	+	+	S	_	Co	S4	Compound	D	W	Ther	Micro	NT	IT, SJ
Convolvulaceae																
Convolvulus arvensis L.	Me	+	+	+	+	H	_	R	S4	Compound	E	W	Ther	Nano	FL	IT, SJ
Cuscuta reflexa Roxb.	Me	+	+	+	+	H	_	R	S2	Leafless	AP	W	Ther	Leafless	FL	IT, SJ
Cyperaceae																
Cyperus rotundus L.	Mo	+	-	+	+	H	_	Co	S4	Simple	D	W	Ther	Lep	NT	IT, SJ, SS
Cannabaceae																
Humulus scandens (Lour.) Merr.	Dr	+	-	+	+	H	_	R	S5	Compound	D	W	Cham	Micro	NT	IT, SJ, SS
Cactaceae																
Opuntia dillenii (Ker Gawl.) Haw.	Me	-	-	+	+	S	+	R	S3	Compound	D	W	Cham	Meso	RE	MED, IT
Caryophyllaceae																
Silene conoidea L.	Me	+	-	-	+	H	+	Co	S4	Simple	D	W	Ther	Micro	OG	MED, SJ
Stellaria media (L.) Vill.	Me	+	-	-	+	H	_	Co	S3	Simple	D	W	Ther	Nano	NT	MED, SJ
Datiscaceae																
Datisca cannabina L.	Me	-	-	+	+	H	_	R	S2	Compound	D	W	Hemi	Micro	OG	SJ, SS
Euphorbiaceae																
Chrozophora tinctoria (L.) A. Juss.	Dr	+	+	-	-	H	_	Co	S2	Compound	D	W	Hemi	Nano	FU	IT, SJ
Croton tiglium L.	Dr	-	-	+	+	S	_	R	S4	Compound	D	C	Geo	Nano	FU	IT
Euphorbia helioscopia L.	Dr	-	+	+	-	H	_	Co	S4	Simple	D	W	Cham	Nano	FL	IT, SS
Euphorbia pilulifera L.	Dr	-	-	+	-	H	_	Co	S2	Simple	D	W	Ther	Nano	FL	IT
Euphorbia prostrata Aiton	Me	-	-	+	-	H	_	Co	S2	Simple	D	W	Ther	Nano	OG	IT, SS
Ricinus communis L.	Me	+	+	+	+	S	_	Co	S1	Compound	E	W	MesoP	Macro	FL	IT, SJ, SS

Ebenaceae															
Diospyros lotus L.	Mo	+	+	+	+	T	_	R	S1	Compound	E	W	MegaP	Nano	MU	IT, SJ, SS
Fabaceae															
Acacia nilotica (L.) Delile	Me	+	+	+	+	T	+	Co	S2	Compound	E	W	MegaP	Micro	DF	IT, SS
Acacia modesta Wall.	Dr	+	+	+	+	T	+	Co	S2	Compound	E	W	MegaP	Micro	DF	IT, SJ, SS
Albizia julibrissin Durazz.	Dr	+	-	+	+	T	_	R	S4	Compound	AP	W	NanoP	Mega	MU	IT
Albizia procera (Roxb.) Benth.	Dr	-	+	+	+	T	_	Co	S1	Compound	D	W	MegaP	Micro	RE	IT, SJ, SS
Albizia lebbeck (L.) Benth.	Dr	-	-	+	+	T	_	Co	S1	Compound	D	W	Megap	micro	FU	IT, SJ, SS
Cassia fistula L.	Dr	+	+	+	+	T	_	R	S3	Compound	E	W	MesoP	Micro	OG	IT
Glycine max (L). Merr	Me	-	-	+	+	S	_	R	S5	Compound	D	C	Ther	Nano	NT	IT
Indigofera heterantha Brandis	Dr	-	+	+	+	S	_	R	S4	Simple	D	W	Nanop	Lep	DF	MED, SJ
Lathyrus sativus L.	Me	+	+	+	-	S	_	R	S4	Simple	D	C	Ther	Nano	NT	IT, SJ
Medicago minima (L.) L.	Dr	-	+	+	-	H	_	Co	S1	Simple	D	W	Ther	Nano	NT	SJ
Medicago polymorpha L.	Me	+	+	+	-	H	_	Co	S1	Simple	D	C	Ther	Nano	NT	SJ
Prosopis juliflora (Sw.) DC	Dr	+	-	+	+	S	+	Co	S1	Simple	D	W	MegaP	Lep	NT	IT
Trigonella foenum-graecum L.	Dr	+	+	-	-	H	_	Co	S3	Simple	D	W	Hemi	Nano	FL	SJ, MED
Juglandaceae															
Juglans regia L.	Me	+	-	+	+	T	_	R	S4	Compound	D	W	MesoP	Nano	DF	IT, SJ
Lamiaceae															
Ajuga brachystemon Maxim.	Dr	-	+	+	-	H	_	Co	S2	Compound	D	W	Ther	Nano	OG	SJ
Mentha arvensis L.	Mo	+	-	+	+	H	_	Co	S5	Compound	D	W	Geo	Nano	OG	IT, SJ
Mentha longifolia (L.) L.	Mo	+	-	+	+	H	_	Co	S3	Compound	D	W	Geo	Nano	OG	IT
Micromeria biflora (Buch. -Ham. ex D.Don) Benth.	Dr	+	+	+	+	H	_	R	S2	Simple	E	W	Ther	Lep	OG	IT, MED
Rydingia limbata (Benth.) Scheen & V.A.Albert	Me	+	+	+	+	S	+	R	S1	Simple	E	W	Ther	Micro	DF	IT
Vitex negundo L.	Me	+	+	+	+	T	_	R	S2	Compound	E	W	NanoP	Meso	RE	IT, SJ
Lythraceae															
Punica granatum L.	Dr	+	+	+	+	T	_	Co	S2	Simple	E	W	Mesop	Nano	MU	IT, MED
Malvaceae															
Bombax Ceiba L.	Me	+	-	+	+	T	+	R	S2	Compound	D	C	NanoP	Micro	MU	IT
Grewia optiva J.R. Drumm. ex Burret	Me	+	-	+	+	S	_	R	S3	Compound	D	W	Mesop	Micro	MU	SJ
Grewia asiatica L.	Me	+	-	+	+	S	_	R	S4	Compound	D	W	Mesop	Micro	MU	SJ
Hibiscus rosa-sinensis L.	Me	+	+	+	+	T	_	R	S2	Compound	E	W	MesoP	Micro	RE	IT
Malva neglecta Wallr.	Me	-	-	+	+	H	_	Co	S1	Compound	D	W	Ther	Nano	FL	SJ
Malva parviflora L.	Me	-	-	+	+	H	_	R	S1	Compound	D	W	Ther	Nano	FL	SJ
Malvastrum bicuspidatum (S. Watson) Rose	Me	-	-	+	+	H	_	R	S1	Compound	D	W	Ther	Micro	OG	SJ
Moraceae															
Broussonetia papyrifera (L.) L'Hér. ex Vent.	Dr	+	+	+	+	T	_	Co	S5	Compound	E	W	NanoP	Micro	FL	IT, SJ
Ficus bengalensis L.	Dr	+	+	+	+	T	_	R	S3	Compound	E	W	Megap	Macro	MU	IT, SJ, SS
Ficus carica L.	Me	+	-	+	+	T	_	Co	S1	Compound	D	W	NanoP	Micro	MU	SJ
Ficus virgata Reinw. ex Blume	Me	+	+	+	+	T	_	R	S1	Compound	E	W	Megap	Macro	MU	MED, SJ, SS
Morus alba L.	Me	-	+	+	+	T	_	Co	S3	Compound	D	W	MesoP	Micro	NT	IT, SJ
Morus nigra L.	Dr	-	+	+	+	T	_	Co	S4	Compound	D	W	MesoP	Micro	NT	IT, SJ
Myrtaceae															
Eucalyptus latisinensis K.D. Hill	Mo	+	+	+	+	T	_	Co	S4	Compound	E	C	MegaP	Nano	NT	SJ
Syzygium aromaticum (L.) Merr. & L.M. Perry	Me	+	+	+	+	S	_	R	S3	Compound	E	W	Cham	Nano	MU	SJ
Menispermaceae															
Tinospora sinensis (Lour.) Merr.	Me	-	-	+	+	H	_	R	S4	Compound	D	W	Cham	Meso	NT	IT, MED
Nyctaginaceae															
Boerhavia diffusa L.	Me	-	-	+	+	H	_	R	S4	Simple	D	W	Ther	Nano	MU	IT, MED
Mirabilis jalapa L.	Mo	+	+	+	+	H	_	Co	S3	Simple	E	W	Geo	Meso	NT	IT, SS

<u>Nitrariaceae</u>																
Peganum harmala L.	Dr	+	+	+	+	H	_	R	S1	Simple	E	W	Cham	Lep	MU	SJ
Oxaliaceae																
Oxalis corniculata L.	Mo	-	-	+	+	H	_	Co	S5	Simple	D	W	Ther	Nano	NT	IT
Oleaceae																
Jasminum officinale L.	Me	+	+	+	+	S	_	R	S3	Compound	E	W	Cham	Lep	NT	IT
Poaceae																
Aegilops cylindrica Host	Me	+	+	-	-	H	_	Co	S4	Simple	D	W	Ther	Lep	NT	IT, SJ
Apluda mutica L.	Me	-	-	+	+	H	_	Co	S5	Simple	D	W	Ther	Lep	MU	COS
Avena fatua L.	Me	+	+	-	-	S	_	Co	S5	Simple	D	W	Ther	Lep	FU	IT, SJ, SS
Bromus diandrus Roth	Me	+	-	+	+	S	_	Co	S3	Simple	D	W	Ther	Lep	NT	IT, SJ
Cymbopogon citratus (DC) Stapf.	Dr	+	-	+	+	H	_	Co	S5	Simple	D	C	Ther	Lep	OG	IT
Cynodon dactylon (L.) Pers.	Dr	+	-	+	+	H	_	Co	S5	Simple	D	W	Ther	Lep	FL	IT, SJ, SS
Dactyloctenium aegyptium (L.) Willd.	Dr	-	-	+	+	H	_	Co	S4	Simple	D	W	Ther	Lep	OG	IT, SJ, SS
Desmostachya bipinnata (L.) Stapf	Dr	+	+	+	+	H	_	Co	S4	Simple	E	W	Ther	Lep	OG	IT, SJ, SS
Dendrocalamus strictus (Roxb.) Nees	Mo	+	+	+	+	T	_	Co	S3	Compound	E	W	NanoP	Micro	OG	COS
Digitaria didactyla Willd.	Me	-	+	+	+	H	_	Co	S5	Simple	D	W	Ther	Lep	OG	COS
Dichanthium annulatum (Forssk.) Stapf	Me	-	+	+	-	H	_	Co	S5	Simple	D	W	Ther	Lep	OG	IT, SJ, SS
Eleusine indica (L) Gaertn.	Me	-	-	+	+	H	_	Co	S5	Simple	D	W	Ther	Lep	OG	COS
Echinochloa crus-galli (L.) P.Beauv.	Me	-	+	+	+	H	_	Co	S4	Simple	D	W	Ther	Lep	OG	IT, SJ, SS
Hordeum vulgare L.	Me	+	+	-	-	S	_	Co	S3	Simple	D	C	Ther	Lep	FU	SJ, IT
Imperata cylindrica (L.) Raeusch.	Me	-	-	+	+	H	_	R	S2	Simple	D	W	Ther	Lep	OG	IT
Lolium temulentum L.	Me	+	+	-	-	H	_	Co	S3	Simple	D	W	Ther	Micro	OG	IT, MED, SS
Poa annua L.	Me	+	+	+	+	H	_	R	S4	Simple	E	W	Cham	Lep	FU	SJ, MED
Pennisetum glaucum (L.) R. Br.	Me	-	-	+	+	H	_	Co	S3	Simple	D	W	Ther	Lep	OG	IT, SJ, SS
Saccharum spontaneum L.	Me	+	+	+	+	S	_	Co	S2	Simple	E	W	Cham	Nano	OG	COS
Saccharum filifolium (Steud)	Me	+	+	+	+	S	_	Co	S2	Simple	E	W	Cham	Nano	OG	IT, MED, SJ
Sorghum halepense (L.) Pers.	Dr	+	+	+	+	H	_	Co	S5	Simple	E	W	Hemi	Nano	NT	IT, SJ, SS
Papaveraceae																
Argemone mexicana L.	Me	+	-	+	+	H	+	Co	S4	Compound	D	W	Hemi	Nano	RE	IT, SJ
Fumaria indica (Hausskn.) Pugsley	Me	+	+	-	-	H	_	Co	S3	Simple	D	W	Ther	Lep	OG	IT
Papaver rhoeas L.	Dr	+	+	+	-	H	_	Co	S3	Compound	D	W	Ther	Nano	RE	MED
Papaver somniferum L.	Dr	+	+	+	+	H	_	R	S2	Compound	E	C	Ther	Meso	CB	SJ
Phyllanthaceae																
Phyllanthus fraternus G.L.Webster	Me	-	-	+	+	H	_	Co	S1	Simple	D	W	Ther	Lep	OG	IT, MED
Polygalaceae																
Polygala abyssinica R. Br. ex Fresen.	Dr	+	+	+	+	H	_	R	S2	Simple	E	W	Ther	Lep	NT	IT, MED
Rumex crispus L.	Dr	+	-	+	+	H	_	R	S2	Simple	D	W	Ther	Macro	RE	IT, SJ
Emex spinosa (L.) Campd.	Dr	-	-	+	+	H	+	Co	S2	Compound	D	W	Hemi	Micro	FU	IT, SS
Pedaliaceae																
Sesamum indicum L.	Me	+	-	-	+	H	_	R	S3	compound	D	W	NanoP	Micro	FU	MED, SJ
Portulacaceae																
Portulaca oleracea L.	Me	-	-	+	+	H	_	R	S2	Simple	D	W	Ther	Nano	FU	MED
Primulaceae																
Anagallis arvensis L.	Me	-	+	+	+	H	_	Co	S3	Simple	D	W	Ther	Nano	FL	MED, SJ
Plantaginaceae																
Lindenbergia indica Vatke	Dr	-	-	+	+	H	+	R	S2	Compound	D	W	Cham	Micro	NT	IT, MED
Misopates calycinum (Lange) Rothm.	Dr	-	-	+	+	H	_	R	S2	Simple	D	W	Ther	Lep	NT	IT, MED

Ranunculaceae																
Ranunculus sceleratus L.	Dr	+	+	+	+	H	_	Co	S3	Simple	E	W	Geo	Nano	FU	IT, SJ
Rosaceae																
Rosa indica L.	Me	+	+	+	+	S	+	Co	S4	Compound	E	W	NanoP	Nano	FU	SJ
Rubiaceae																
Galium aparine L.	Me	-	-	+	+	H	_	R	S2	simple	D	W	Ther	Nano	MU	IT, SJ
Rhamnaceae																
Ziziphus jujuba Mill.	Dr	+	+	+	+	T	+	Co	S4	Simple	E	W	NanoP	Micro	NT	IT, SJ
Ziziphus nummularia (Burm.f.) Wight & Arn.	Me	+	+	+	+	T	+	Co	S1	Simple	E	W	NanoP	Micro	NT	SJ
Rutaceae																
Citrus medica L.	Me	+	+	+	+	T	+	Co	S3	Compound	E	C	Nanop	Micro	FU	SJ
Zanthoxylum armatum DC.	Dr	+	+	+	+	T	+	R	S3	Compound	E	W	NanoP	Micro	FL	IT, SJ, SS
Solanaceae																
Brugmansia arborea (L.) Steud.	Me	+	-	+	+	S	_	R	S3	Simple	D	W	Hemi	Micro	NT	IT, MED
Cestrum diurnum L.	Me	+	+	+	+	S	_	R	S1	Simple	E	W	Cham	Micro	NT	IT
Cestrum nocturnum L.	Dr	+	+	+	+	S	_	R	S3	Simple	E	W	Cham	Micro	NT	IT
Datura innoxia Mill.	Me	+	-	+	+	H	+	R	S4	Compound	D	W	Cham	Macro	OG	IT, MED
Datura stramonium L.	Me	-	-	+	+	S	+	R	S3	Compound	D	W	Cham	Macro	NT	IT, MED
Solanum americanum Mill.	Me	+	-	+	+	H	_	Co	S3	Compound	D	W	Ther	Micro	NT	COS
Solanum surattense Burm. f.	Me	+	-	+	+	H	+	Co	S4	Compound	D	W	Ther	Micro	NT	SJ, SS
Withania somnifera (L.) Dunal.	Dr	-	-	+	+	S	_	R	S4	Compound	D	W	Cham	Meso	MU	IT, MED, SJ
Sapindaceae																
Dodonaea viscosa (L.) Jacq.	Dr	+	+	+	+	S	_	Co	S4	Compound	E	W	Cham	Nano	DF	COS
Simaroubaceae																
Ailanthus altissima (Mill.) Swingle	Me	+	-	+	+	T	_	Co	S3	Compound	D	W	NanoP	Nano	FU	IT, SJ
Scrophulariaceae																
Verbascum thapsus L.	Dr	-	-	+	+	H	_	R	S3	Simple	D	W	Ther	Meso	FL	SJ
Salicaceae																
Populus alba L.	Me	-	+	+	+	T	_	Co	S3	Compound	D	W	MegaP	Meso	NT	IT, SJ, SS
Tamaricaceae																
Tamarix aphylla (L.) H. Karst.	Me	+	+	+	+	T	_	Co	S2	simple	E	W	Megap	Lep	NT	MED, SJ
Verbenaceae																
Lantana camara L.	Mo	+	+	+	+	S	+	Co	S3	Compound	E	W	Nanop	Nano	FL	SJ
Verbena officinalis L.	Me	+	+	+	+	H	_	R	S4	Compound	E	W	Ther	Micro	NT	IT, SJ
Violaceae																
Viola aberrans Greene.	Dr	+	-	+	+	H	_	R	S3	Compound	D	W	Cham	Nano	OG	IT, SJ
Vitaceae																
Vitis vinifera L.	Mo	-	-	+	+	S	_	R	S4	Compound	D	W	NanoP	Meso	OG	IT, SJ
Xanthorrhoeaceae																
Asphodelus tenuifolius Cav.	Me	+	-	+	+	H	_	R	S2	Simple	D	W	Hemi	Lep	OG	IT, MED
Zygophyllaceae																
Fagonia cretica L.	Me	+	+	+	+	H	+	Co	S2	Simple	E	W	Ther	Lep	FL	IT, SJ, SS
Tribulus terrestris L.	Me	-	+	+	+	H	_	R	S4	Simple	D	W	Hemi	Nano	FL	IT, SJ, SS

Key Legends: **Habitat**: Me: Mesic; Mo: Moist; Dr: Dry. **Seasons**: A: Autumn; W: Winter; SP: Spring; SM: Summer. **Abundance**: R: Rare; Co: common. **Habit:** H: Herb; S: Shrub; T: Tree. **Leaf persistence**: E: Evergreen; D: Deciduous; Ap: Aphyllous; **Cultivation status**: W: Wild: C: Cultivated; **Life-form**: C: Chamaephytes; Ge: Geophytes; Hemi: Hemicryptophytes; NanoP: Nanophanerophytes; Mesop: Mesophanerophytes; MegaP: Megaphanerophytes; Ther: Therophytes; **Leaf Form**; Nano: Nanophyllous; Micro: Microphyllous; Meso: Mesophyllous; Mega: Megaphyllous; Macro: Macrophyllous Lep: Leptophyllous. **Threats**: NT: No threat; FL: Flood; DF: De-forestation; MU: Medicinal uses; OG: Over grazing; FU: Fuel uses; RE: Road extension; CB: Cultivation Banned. **Chorotype**: IT: Irano-Turanian; MED: Mediterranean; SJ: Sino-Japanese; SS: Saharo-Sindian; COS: Cosmopoliton.

(Table 3).

Spines and abundance

Among the collected species, 28 (16.1 %) had spines on the body surface and the remaining 145 species (83.8 %) were spineless. However, among the 173 plant species, 100 (57.8 %) were found common in the area and 73 (42.1 %) were rare (Table 3).

Sociability

Sociability is based on the closeness between the individuals in the area examined. S1 stands for those individuals who are found singly. In our study 26 species (15.02 %) were S1, 36 species (20.8 %) were found in small groups (S2). The S3 individuals were found in small patches (45 plant species, 26.01 %). The remaining S4 individuals were found in large patches in study siregionte (40 plant species, 23.12 %), while 25 plant species (14.4 %) belonged to S5 and individuals were found in aggregated populations (Table 3).

Leaf type and persistence

Most species (78 species, 45.08 %) had simple leaves and 90 species (52 %) had compound leaves, while scaly leaf and leafless types were found in 2 species (1.15 %) each and one species had feathery leaves (0.57 %). Out of the 173 species, 115 species (66.4 %) were deciduous while 55 (31.7 %) had persistent leaves and 3 species (1.7 %) were aphyllous. Most (157, 90.7 %) species were wild and only few cultivated 17 (9.2 %) (Table 3).

Life form and leaf size

Of all species, 69 were therophytes (39.8 %), followed by Chameophytes (28 species, 16.1 %), Hemicryophytes (25 species, 14.4 %), 8 species (6.9 %) were Geophytes. Phanerophytes included 43 species (24.8 %). According to Raunkiaer life forms the Phanerophytes were categorized into 3 categories, namely Nanophanerophytes with 18 species (10.4 %), Mesophanerophytes with 13 species. Th leading leaf spectrum was nanophyllous with 58 species (33.5 %), followed by microphyllous (49 species, 28.3 %), leptophyllous (42, 24.2 %), mesophyllous (10 species, 5.7 %), macrophyllous (9, 5.2 %), megaphyllous (3 species, 1.73 %) and 2 species were leafless (1.55 %) (Table 3).

Threats

The flora of the study area is facing a variety of threats. Fourty -one species (23.6 %) was affected by over-grazing, followed by 26 species (15.02 %) found on the banks of rivers and streams and facing floods threats. Twenty-four species (13.8 %) were facing overcollection as medicinal plants, followed by 15 species (8.69 %) endangered by deforestation and 14 species (8.09 %) used as fuel wood. Out of the 173 plant species only 44 species (25.4 %) were in suitable environmental conditions and did not face any threats (Table 3).

Chorotype analysis

The chorological analysis showed 3 regions with species mostly uni-regional, followed by bi-regional and pluri-regional. A total of 54 species was uni-regional as (31.2 %), with 23 species (13.2 %) being Irano-Turanian (IT), followed by 22 species (12.3 %) which were Sino-Japanese (SJ) and 4 species (2.31 %) of Mediterranean nature (MED). Seventy-four species were bi-regional (42.7 %) with 34 species (19.6 %) bi-regional (IT, SJ), followed by 13 species (7.51 %) each in (IT, MED) and (MED, SJ), 8 species (4.6 %) were Irano-Turanian and Saharo-Sindian (IT, SS) and 3 species (1.7 %) each belonged to (MED, SS) and (SJ, SS). A total of 35 species (20.2 %) were pluri-regional, with 28 species (16.1 %) belonging to (IT, SJ, SS), followed by 4 plant species (2.31 %) in (IT, MED, SJ), while 2 species (1.15 %) belonged to (IT, MED, SS) and one plant species fell into (0.75 %) (MED, SJ, SS). In the assessment 15 plant species (8.67 %) showed the worldwide distribution and could be considered as Cosmopolitan (Table 2).

Diversity indices

Alpha

The species abundance heatmap reveals distinct patterns of alpha diversity across 4 tehsils as measured by the Shannon Index. Tehsil-Topi exhibits the highest overall species abundance and diversity, indicated by more intense red coloration, particularly for several species at the bottom of the chart. Tehsil-Swabi and Tehsil-Razzar show moderate levels of diversity, with patchy distributions of species abundance. Tehsil-Lahor demonstrates the lowest overall diversity, with fewer intense red spots and more white areas indicating lower abundance or absence of species. Notably, a few species show high abundance across all 4 tehsils, appearing as horizontal red bands, suggesting these may be generalist or widespread species in the region. The heatmap also highlights considerable variation in species composition between tehsils, with some species abundant in one area but scarce or absent in others, indicating potential environmental or ecological factors influencing species distribution. This visualization effectively captures the complexity of biodiversity patterns across the study area, providing insights into both common and rare species occurrences in different localities (Fig. 2).

Beta

The Bray-Curtis Dissimilarity Heatmap reveals relationships among 8 plant species such as *Acacia nilotica*, *Prosopis juliflora*, *Capparis decidua*, *Ziziphus nummularia*, *Salvadora oleoides*, *Tecomella undulata*, *Calligonum polygonoides* and *Leptadenia pyrotechnica*. The color-coded visualization, ranging from blue (low dissimilarity) to red (high dissimilarity), illustrates similarity patterns between species pairs. Notable features include the blue diagonal indicating self-similarity and larger blue blocks suggesting groups of similar species. Dissimilarity values range from 0 - 0.8, with dendrograms on both axes showing hierarchical clustering. This heatmap provides a quantitative and visual assessment of ecological relationships within the studied plant community (Fig. 3).

Gamma

The total species richness is carried mean the gamma diversity were analyzed throughout the district. Topi exhibits the highest species richness with 172 unique species, which coincides with the overall gamma diversity of the region. There's a notable increasing trend in species count from Razzar (151 species) through Swabi (165 species) to Topi. Interestingly, Lahor shows a relatively high species count of 162, creating a non-linear pattern across the tehsils. The gamma diversity line at 172 species indicates the total richness across all tehsils combined. This pattern suggests that while individual tehsils have varying levels of biodiversity, with Topi being the most diverse, the collective

Fig. 2. Heatmap representing the Shannon index of similarity composition among plant species in district Swabi, Khyber Pakhtunkhwa, Pakistan.

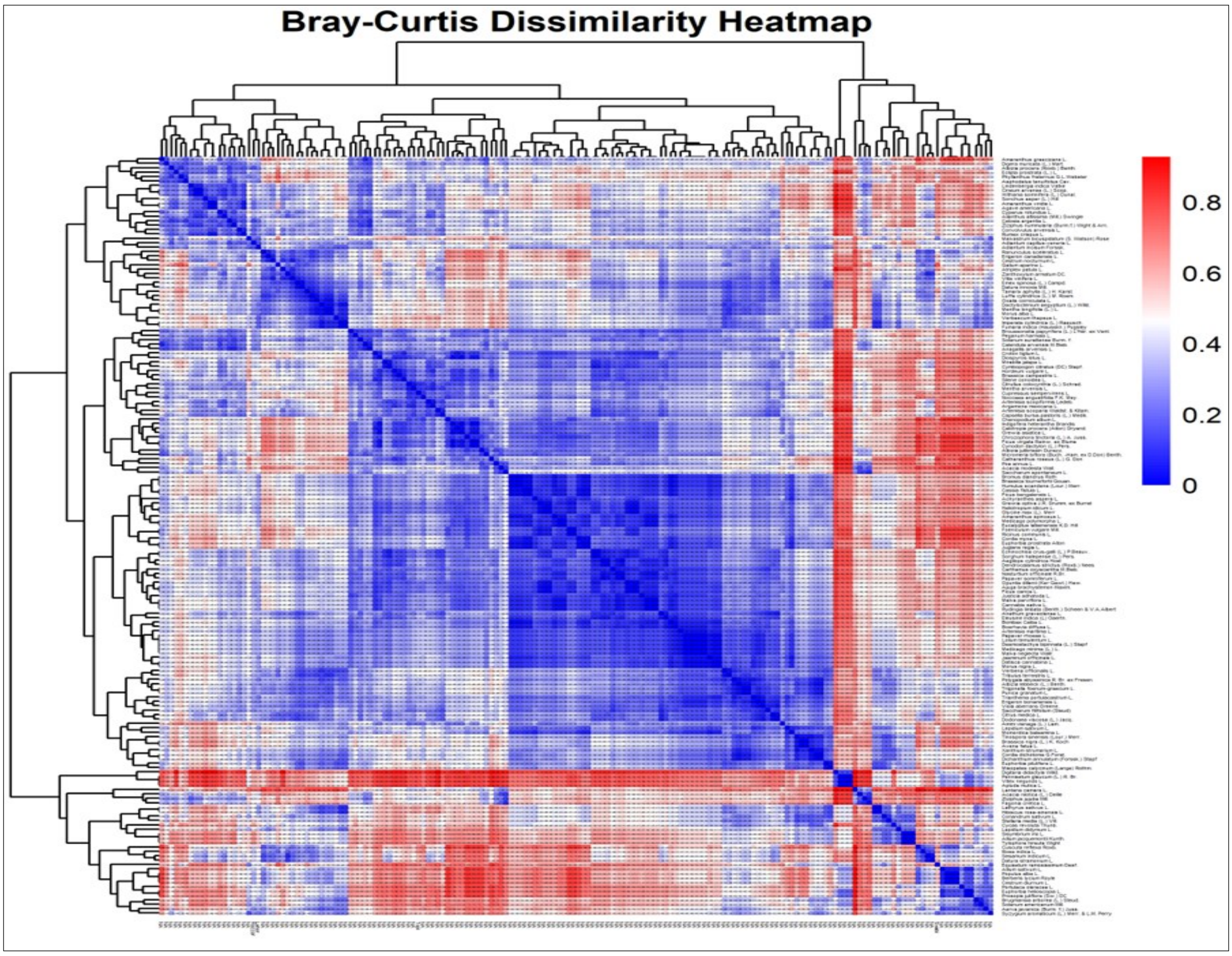

Fig. 3. Bray-Curtis Dissimilarity Heatmap of plant species in district Swabi, Khyber Pakhtunkhwa, Pakistan.

biodiversity of the region is higher than any single tehsil, highlighting the importance of conserving species across all areas to maintain overall biodiversity (Fig. 4).

Species-Area Curves

The Species-Area Curve analysis for district Swabi, Khyber Pakhtunkhwa, Pakistan, reveals intriguing biodiversity patterns across its 4 tehsils: Topi, Razzar, Swabi and Lahor. As illustrated in (Fig. 5), the species richness values cluster closely, ranging from approximately 3.95 to slightly above 4.00, indicating a relatively uniform distribution of biodiversity across the district. Notably, Tehsil Topi exhibits a marginally higher species richness, surpassing the 4.00 threshold, while the other tehsils (Razzar, Swabi and Lahor) show values just below 4.00. This subtle variation suggests that while the overall ecological conditions might be similar across the district, there could be localized factors in Topi contributing to its slightly elevated biodiversity. These findings underscore the importance of considering both district-wide and tehsil-specific approaches in biodiversity conservation efforts. The consistency in species richness across most of the district may indicate a well-adapted and resilient ecosystem, but it also highlights the need for vigilant conservation practices to maintain this balance. Further research into the specific environmental, geographical, or anthropogenic factors influencing these patterns could provide valuable insights for targeted conservation strategies and sustainable resource management in district Swabi (Fig. 5).

PCA

The Principal Component Analysis (PCA) offers valuable insight into the overall predictions regarding plant diversity. The PCA biplot displays 2 principal components: Dimension 1 (Dim1) explains 44.5 % of the variance, while Dimension 2 (Dim2) accounts for 25.5 %. Data points represent individual observations influenced by significant variables, such as "Tehsil-Lahor," "Tehsil-Topi," and "Tehsil-Swabi," as indicated by the vectors originating from the center. The scree plot shows a sharp decline in variance explained by the first 2 components, underscoring their critical role in capturing the dataset's structure. In the PCA variable plot, the lengths and directions of the vectors reflect the contributions of each variable to the principal components, with those near the unit circle indicating a stronger influence. The distribution of specific plant species in the PCA individual points plot further highlights the variability in diversity across different tehsils. Collectively, these plots indicate that geographical factors significantly influence plant diversity and variations may also arise due to anthropogenic activities, leading to distinct patterns among the various tehsils (Fig. 6).

Discussion

The observation of plant diversity and ecological features of flora provides a comprehensive understanding of the vegetation within a specific area or geographic zone, encompassing habitats, vegetation diversity and patterns at regional and global scales (24–27). The current study offers an initial approach for identifying the vegetation profile and conservations stance within district Swabi, highlighting the importance of implementing targeted conservation strategies. Such strategies are crucial for preserving plant diversity, supporting ecosystem dynamics, enhancing ecological stability and protecting essential resources for both local ecosystems and broader environmental sustainability (28, 29). Our results represent the first vegetation inventory, biological spectra, phenology, threats

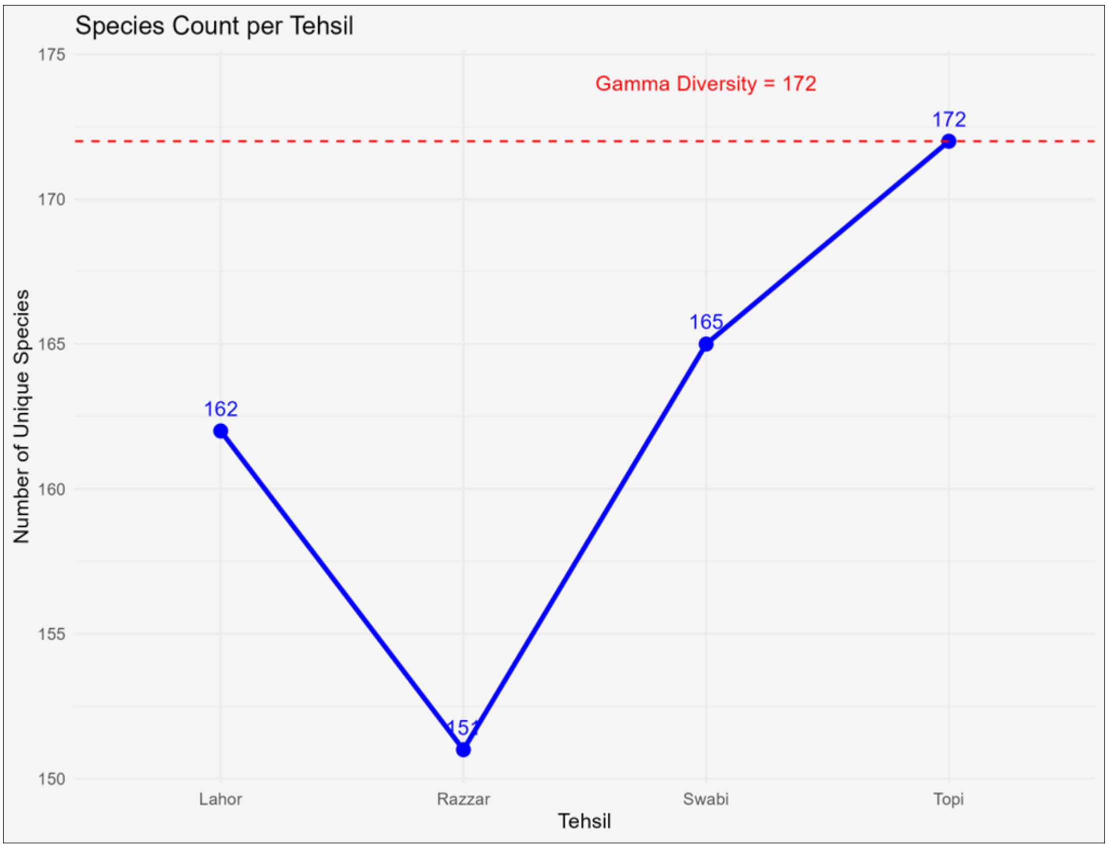

Fig. 4. Distribution of species counts reflecting gamma diversity across the 4 tehsils: Lahor, Razzar, Swabi and Topi.

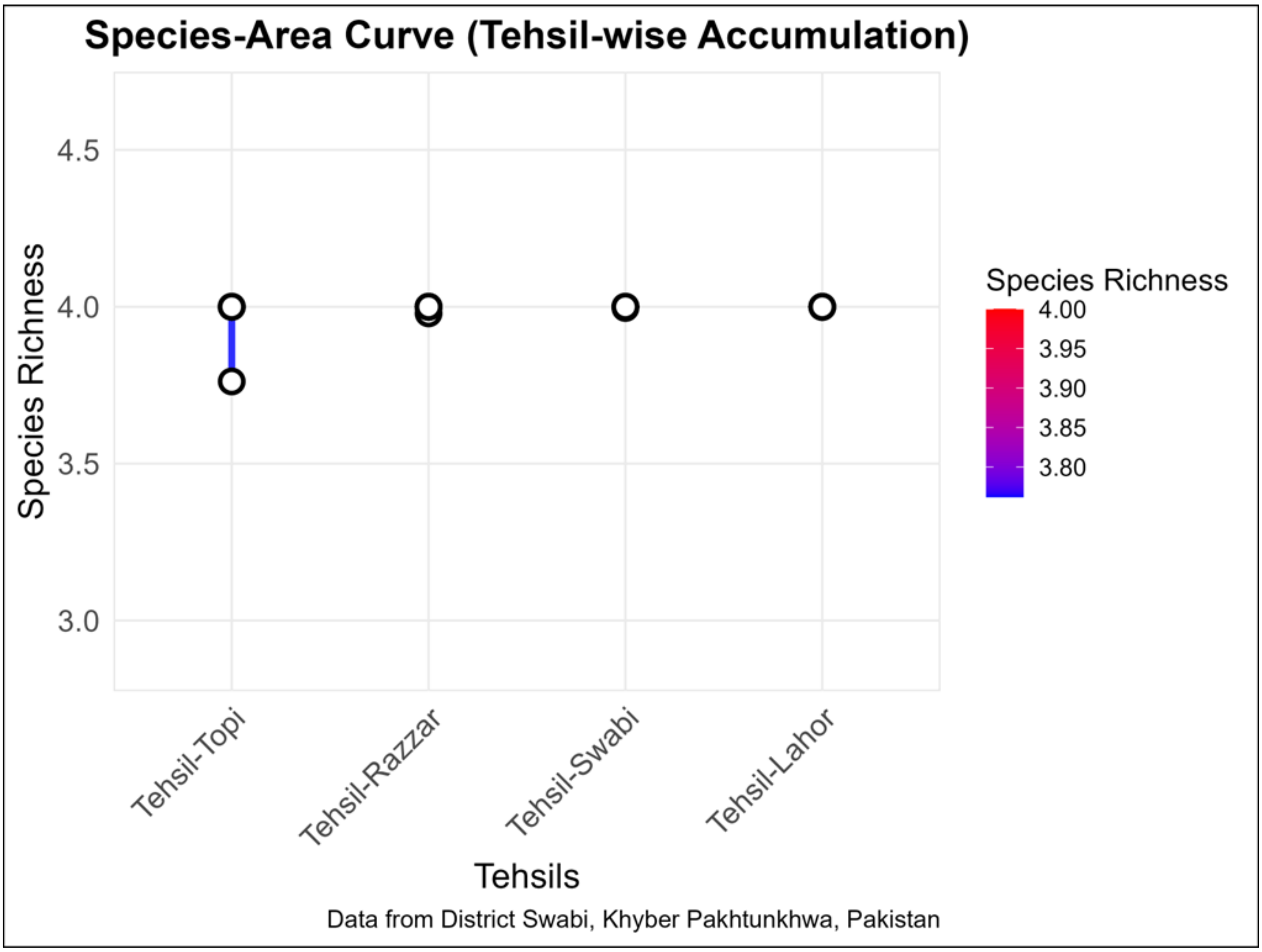

Fig. 5. Species-Area Curves analysis reveals distinct patterns of species accumulation across the studied Tehsils.

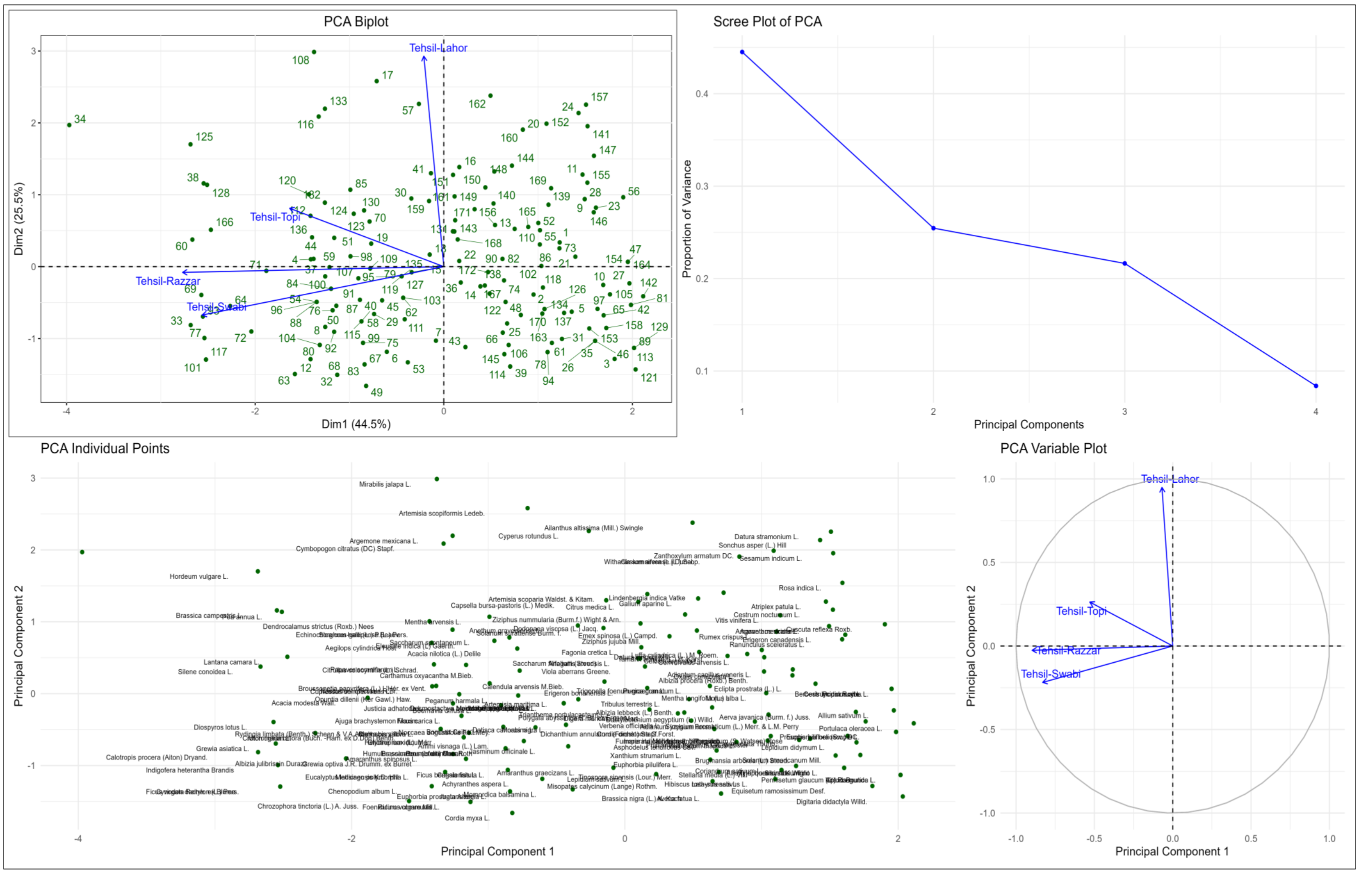

Fig. 6. Ordination plots of plant species abundance data from 4 tehsils in district Swabi: Lahor, Razzar, Swabi and Topi. The plots display the results of Principal Component Analysis (PCA).

to diversity, habits, leaf type, habitat, distribution and chorological analysis of district Swabi, Khyber Pakhtunkhwa, Pakistan. The results of the study are comparable to adjacent areas, suggesting similar ecological patterns and plant diversity trends (30). The interpretation of biological spectra and leaf size reflects the climatic conditions (31, 32). These physiognomic data are vital for identifying the biotic interactions of plant diversity and similarities in biological composition indicate similar climatic conditions (29, 33). The vegetation of the current study was dominated by therophytes with 69 species (39.8 %), followed by the Chameophytes with 28 species (16.1 %), indicating biotic pressure and anthropogenic activities such as overgrazing. Our assessment showed that 41 species (23.6 %) were facing overgrazing, 26 species (15.02 %) flood threats, 24 species (13.8 %) overexploitation as medicinal plants, 15 species (8.69 %) were facing to deforestation and 14 species (8.09 %) were threatened being harvested as fuel wood (34–37). Similar work has been carried from adjacent areas (38–41). The leading leaf spectrum was nanophyllous with 58 species (33.5 %), followed by microphyllous with 49 species (28.3 %) similar to earlier report which documented nanophyllous as the dominant leaf size spectrum, whereas another study stated that leptophyllous, nanophyllous and microphyllous were the dominant leaf spectrum (42, 43). Previous studies also reported nanophyllous and microphyllous as dominant leaf spectra (44, 45). In our data 28 species (16.1 %) had spines. In our assessment the vegetations as well adopted to the mesic habitat with 99 species (57.2 %), while 59 species (34.1 %) were growing in dry habitat, including the 115 (66.4 %) were deciduous, while 55 (31.7 %) had permanent leaves and 3 species (1.7 %) were aphyllous, these findings are showing the diversity and dominate flora as per previous study of (13). Previously, the (46) reported the coexistence of evergreen and deciduous oaks, to adjust their phenology with stressful Mediterranean summers. The current study provides baseline of the data for conservation of vegetation diversity similar to previous studies (47–50). In current study 15 species (8.6 %) were found in moist habitats, similar to previous reports (51, 52). Another study stated that Irano-Turanian was the most common chorotype (49, 53, 54). The analysis of species abundance across Lahor, Razzar, Swabi and Topi tehsils shows distinct biodiversity patterns. Topai has the highest alpha diversity (Shannon index: 1.946), followed by Razzar and Topi, with lahor showing the lowest diversity by observing form the previous assessed study (55). Beta diversity indicates similar species compositions between Lahor-Razzar and Razzar-Swabi, while Swabi exhibits greater ecological differentiation as previous work (16). Overall gamma diversity across the tehsils is 2.197 which were similar to previously (56). Species-specific preferences include *Adiantum capillus-veneris* (3.25 per plot), *Cupressus sempervirens* (7.5), *Equisetum ramosissimum* (5.75) and *Datura stramonium* (4.2) (12). Species-abundance patterns vary, with Lahor dominated by a few species, Razzar showing more even distribution, Swabi balanced and Topi initially diverse but later dominated by a few species. Ordination techniques (PCA, CA, DCA, CCA) reveal distinct species clustering and significant environmental correlations, explaining 65 % of variance overall and 40 % along the primary axis (57). The distinct biodiversity patterns across district Swabi tehsils are influenced by varying biotic and abiotic factors, including climatic conditions and human activities like overgrazing and deforestation. These factors shape species richness, composition and distribution, with a dominance of therophytes and nanophyllous species indicating adaptation to local habitats. This study provides essential baseline data for conservation efforts. Albeit these findings point to the ecological significance of environmental factors in shaping plant community structure in district Swabi, essential for biodiversity conservation efforts.

Conclusion

This study provides a comprehensive assessment of plant diversity in district Swabi, revealing a rich and varied flora across its 4 tehsils. Our findings highlight the dominance of angiosperms and a diverse range of life forms, with a notable prevalence of mesic habitats. The analysis indicates distinct ecological gradients and community structures, as evidenced by PCA, CA, DCA and CCA results. High alpha and gamma diversity values shows the ecological significance of the area, while beta diversity analysis illustrates unique species compositions among the tehsils. The identified threats, including over-grazing and habitat fragmentation, emphasize the need for targeted conservation strategies. The chorotype analysis offers valuable insights into the distribution patterns of species, contributing to a deeper understanding of the region's biogeography. Overall, this study explains the importance of preserving plant diversity in district Swabi and provides a foundation for future conservation and research efforts.

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Authors' contributions

FU designed the study conception and framework, performed the experimental research, interpreted the results and drafted the manuscript. MI encouraged the first author to conceive the presented idea and supervised the project. JS and WA contributed to the research design and supervised the findings of this work. MS performed data analysis, RZ revised the manuscript, SK and SK helped in funding. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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