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FLORISTIC DIVERSITY AND PHYTOSOCIOLOGICAL ANALYSIS OF TAKKAR WILDLIFE SANCTUARY DISTRICT KHAIRPUR, SINDH, PAKISTAN

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Abstract

Biodiversity is of paramount importance to human society as it provides essential ecosystem services. Floristic diversity, a key source of botanical knowledge, plays a critical role in the conservation of ecological resources. This study aimed to assess the phytosociological aspects of the previously unexplored Takkar Wildlife Sanctuary in the Khairpur District. We conducted a sampling of 30 sites to evaluate the vegetation structure of the study area. Vegetation data were collected utilizing the quadrat method, with 20 × 20 m quadrats designated for shrubs and trees, and 2 × 2 m quadrats for herbaceous species. The Takkar Wildlife Sanctuary exhibited significant diversity in its flora, comprising 81 species across 34 families and 68 genera. The Poaceae family emerged as the most dominant, featuring 13 species (16%), closely followed by Fabaceae with 11 species (14%). Herbs and grasses constituted the majority of the flora, accounting for 59 species (72.8%) of the overall floristic composition, followed by shrubs (11 species, 13.5%). Perennial (50 species, 61.7%) were the most common lifespan category in the floristic composition, followed by annual (31 species, 38.2%). Based on the biological spectrum, Therophytes were the most dominant, representing 31 species (38.2%) of the total flora, followed by phanerophyte (20 species, 24.6%). The prevalence of therophytes indicates a region under high biotic pressure. Four species - *Haloxylon salicornicum* (Amaranthaceae), *Aristida adscensionis* (Poaceae), *Prosopis juliflora* (Fabaceae), and *Capparis decidua* (Capparaceae) - were identified as the most frequent species. TWINSPAN classification clustered the vegetation plots based on soil characteristics, identifying 20 distinct plant communities. Notably, one species, *Tecomella undulata*, was found to be globally threatened and classified as Endangered (EN) by the International Union for Conservation of Nature. This research provides current information on the area's floristic richness, which may be beneficial for future plant conservation efforts.

Key words: IUCN status; Plant community; TWINSPAN classification; Threatened species; Sindh

Introduction

Pakistan is characterized by a rich natural floristic diversity, featuring more than 6,000 flowering plant species, of which more than 300 are endemic (Qazi *et al*., 2023). This diversity can be attributed to the country's varied topographical, geological and climatic conditions (Ali & Qasier, 2012; Shabbir & Jabeen, 2012). These plant species provide significant ecosystem services that are vital for sustainable ecosystems (Sheikh *et al*., 2002; Alanís-Rodríguez *et al*., 2017; Mangi *et al*., 2023, Sirohi *et al*., 2025). However, the populations of these plants have declined due to several factors, including deforestation, overgrazing, soil erosion, and the reliance of local communities on these plants (Shaheen *et al*., 2014). Consequently, the ongoing destruction of natural habitats is leading to a continuous depletion of floral diversity, which threatens the extinction of various flora and fauna (Perveen & Hussain, 2007). Therefore, it is imperative to document plant populations and conserve floristic diversity. The study of floristic diversity, composition, distribution, and competition is not only valuable for botanists, geographers, environmentalists, and conservationists but is also essential for chemists, biochemists, biotechnologists, and pharmacists due to the medicinal importance of these plants (Abbasi *et al*., 2013).

Ecologists from Pakistan and around the world have documented the floristic composition of diverse communities (Abd El-Ghani and Abdel-Khalik, 2006; Mwakalukwa *et al*., 2014; Tadesse *et al*., 2017; Moradi and Attar, 2018; Hassan and Hassan, 2019; Ahmed *et al*., 2019; van Rooyen *et al*., 2019). Numerous anthropogenic activities pose a significant threat to these valuable habitats and their vegetation (Linderman *et al*., 2006; Elshatshat & Mansour, 2014; Majid *et al*., 2015). The health of habitats is closely correlated with the floristic diversity of the area (Rehman *et al*., 2017). Several studies have indicated that continuous assessment of biodiversity is essential, particularly for xeric ecosystems (Kairis *et al*., 2015). The floristic diversity of arid and hilly areas in the upper Sindh Province of Pakistan is less diverse than in other regions of the country due to several factors, including low rainfall, poor soil quality, grazing, and the cutting of plants for fuel, eventually contributing to the decline in floristic diversity (Perveen & Hussain, 2007).

Numerous studies provide baseline information on floristic composition, taxonomic assessment, phytosociology, and ethnobotany across various regions of the country (Ahmed *et al*., 2013; Majid *et al*., 2019; Khaskheli *et al*., 2022). However, there has been limited research conducted in Sindh Province, with only a few studies documenting the floristic composition of different habitats within this area (Ansari & Mahar,

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1993; Miller *et al.*, 2005; Qureshi, 2008; Qureshi *et al*., 2010; Qureshi & Ahmad, 2010; Qureshi & Bhatti, 2010; Sirohi *et al*., 2019; Saand *et al*., 2019). Anthropogenic activities have significantly reduced plant diversity, particularly in hilly and desert regions where vegetation regeneration is severely hampered by physiographic and climatic constraints, as well as a lack of awareness regarding the impacts of anthropogenic activities (Ansari *et al*., 2017; Jatoi *et al*., 2019; Faiz & Abas, 2019). It is essential to gather data on the floristic composition of these sites and evaluate the potential effects of anthropogenic activities on floral communities (Siddiqui *et al*., 2016). To our knowledge, no prior studies have been conducted on the floristic diversity and phytosociological analysis of the Takkar Wildlife Sanctuary in District Khairpur, Sindh, Pakistan. This study aimed to assess the floristic diversity, community composition, and ecological classification of plant species in Takkar Wildlife Sanctuary. It also evaluated distribution patterns and conservation status to enhance understanding of habitat heterogeneity and provide baseline data for future biodiversity conservation and management efforts in the wildlife sanctuary.

Materials and Methods

Study area: The Takkar Wildlife Sanctuary, encompassing an area of 43,000 hectares in the Khairpur district, is situated in the southern region of Sindh province (Fig. 1). The sanctuary experiences a subtropical climate, characterized by semi-arid conditions and extreme heat. The mean annual rainfall varies up to 125 mm. Average winter temperatures can reach as low as 7°C, while summer temperatures may rise as high as 45°C (Anon., 2021). This area is defined by low humidity levels and a high rate of evaporation.

Field survey: Thirty sites were randomly selected for vegetation sampling. We delineated the study area and overlaid a grid on the map to systematically organize potential sampling locations. Random numbers corresponding to the grid cells were generated using Microsoft Excel, and 30 sites were selected through this randomization process. During site selection, we ensured that all chosen locations were both physically accessible and safe for fieldwork. Plant species were recorded using the quadrat method, with ten quadrats randomly placed at each site throughout the Wildlife Sanctuary. Herbaceous vegetation was assessed using a 2 x 2 meter quadrat, while larger quadrats measuring 20 x 20 meters were utilized for evaluating shrub and tree communities (Rodwell, 1992).

Collection, identification, and preservation of plant species: Species identification was conducted in the field whenever feasible, and unidentified specimens were subsequently transported to the Herbarium for further confirmation. In accordance with standard protocol, herbarium sheets were prepared for each plant specimen (Bridson & Forman, 1992). Species identification utilized the Flora of Pakistan in conjunction with various taxonomic literature, floral studies conducted in the Nara Desert, and the flora of Karachi (Jafri, 1966; Qureshi, 2012; Bhandari, 1987; Batanouny, 1987; Anon., 2020). To support future research and serve as a reference point, these herbarium sheets were deposited at the Herbarium of Shah Abdul Latif University, Khairpur, Sindh, Pakistan. A comprehensive list of plant species was compiled, including vernacular names, botanical names, family names, habitat descriptions, life forms, and life spans. Raunkiaer's system of classification (Raunkiaer, 1934) was employed to categorize plant species based on the position of their perennating buds.

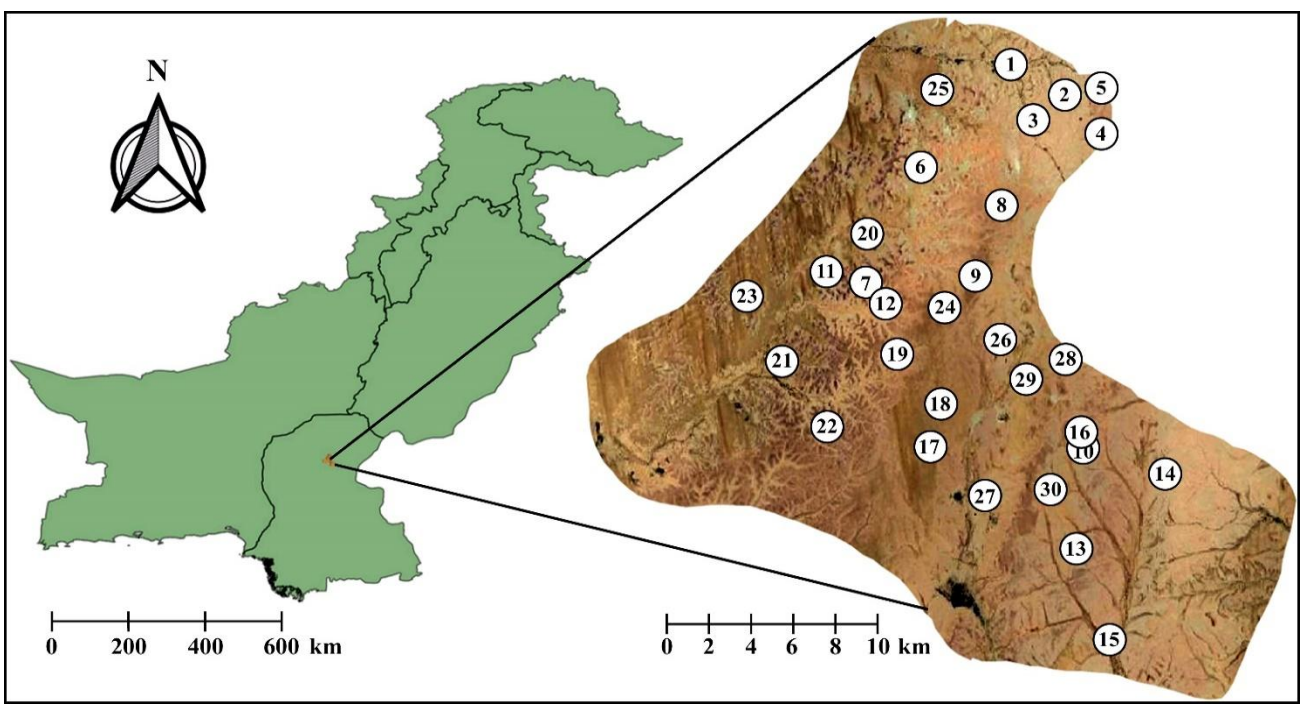

Fig. 1. Distribution of the sampling location within the boundaries of study area (Takkar Wildlife Sanctuary) and the location of study area in Sindh Province of Pakistan.

Plant community parameters: The measurement of the rarefaction curve was conducted using EstimateS 9.1 software (Colwell, 2013). Additionally, the Morista-Horn similarity index was employed to assess the uniformity of vegetation throughout the habitat (Chao *et al*., 2006). To gauge species diversity within the habitat, Simpson's diversity index was applied (Magurran & McGill, 2011). The phytosociological characteristics of the plant community were computed using data gathered from quadrats. The calculation of phytosociological attribute values was conducted using the following formula:

$$\text{Frequency (F)} \quad \frac{\text{Total number of quadrats in which species occur}}{\text{Total number of quadrats used for sampling}}$$

$$\text{Relative frequency (RF)} \quad \frac{\text{Frequency of a species}}{\text{Total frequency values of all species}} \times 100$$

$$\text{Density (D)} \quad \frac{\text{Total number of individuals of species occur in all quadrats}}{\text{Total number of quadrats}}$$

$$\text{Relative density (RD)} \quad \frac{\text{Total number of individuals of a species}}{\text{Sum of the densities of all species}} \times 100$$

After determining the relative frequency of each species, diverse plant species were categorized into Raunkiaer's five frequency classes based on their frequency values, as presented in Table 1 (Rodwell, 1992). The ecosystem's core species were identified, with regionally prevalent and abundant species classified as core species based on their ecological distribution. Two-way indicator species analysis (TWINSPAN) was utilized to examine the vegetation data through the R package TWINSPAN (Hill *et al*., 1979; Oksanen & Hill, 2024; R Core Team, 2024).

Table 1. Raunkiaer's classes of frequency of species.

S. No.	Frequency class	Frequency value (%)	Rarity
1.	Class I	0-20	Very rare
2.	Class II	20-40	Rare
3.	Class III	41-60	Infrequent
4.	Class IV	60-80	Abundant
5.	Class V	81-100	Very abundant

Result

Taxonomic diversity of flora: The flora of the Takkar Wildlife Sanctuary included a total of eighty-one (81) plant species, distributed across 34 families and 68 genera (Table 2). Notably, over 51% of the plant species belonged to the families Poaceae, Fabaceae, Zygophyllaceae, Amaranthaceae, and Asteraceae. Additionally, nine families were represented by two species each. It was noted that more than 50% of the plant families were represented by a single species within the overall floristic composition (Fig. 2). Among the plant genera, *Heliotropium* was prominent with four species, while *Prosopis* and *Fagonia* each had three species. The genera *Vachellia*, *Aristida*, *Haloxylon*, *Tamarix*, *Tribulus*, and *Salvadora* each account for two species. The remaining forty-two genera were represented by a single species (Table 2).

During the initial stages of the surveys, the rarefaction species curve demonstrated a rapid increase, primarily due to the abundance of common species. Approximately 75% of the recorded species were documented within the first hundred quadrats. Furthermore, there was a low potential for the discovery of new species if additional samples are incorporated (Fig. 3). The species richness estimator (Chao 1) estimated a total of 85.5 (SD 4.51) species, which was in close agreement with the 81 species observed in the field. The number of species present at each site varied from 4 to 28, with the majority of sites hosting up to ten species (Fig. 4). The estimated species richness (Chao 1) per site also closely aligned with observed species, ranging between 4 and 32.5 (Fig. 4). The mean number of observed species across sites was 9.3; however, most study sites contained between five and ten species (Fig. 5a). The diversity of species varied from 0.22 to 0.94 across various study sites (Fig. 4), with a mean diversity of 0.704 overall (Fig. 5b). The vegetation is sparse and diverse, with the sites sharing a mean of 1.7 species (SD = 1.8) (Fig. 5c). Similarly, the Morisita-Horn similarity index indicated significant heterogeneity among various areas in the Takkar Wildlife Sanctuary. The similarity index ranged from 0% to 85% among the sites (Table 3), with the mean similarity across the sites being 14%. Most of the sites exhibited less than 30% similarity in their vegetation patterns (Fig. 5d).

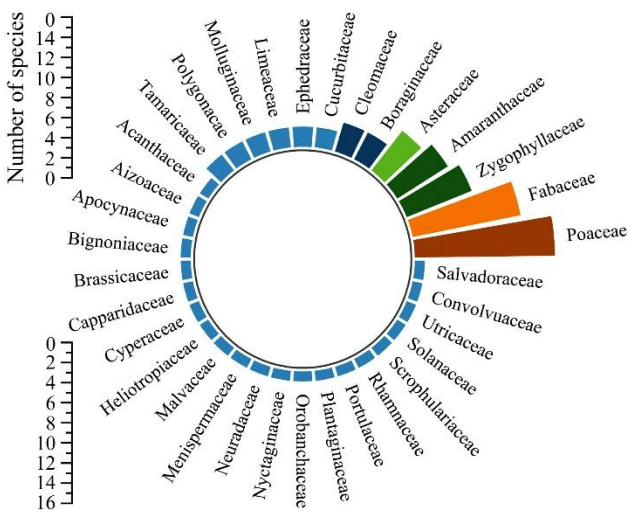

Fig. 2. Plant families and species richness of Takkar Wildlife Sanctuary Khairpur District.

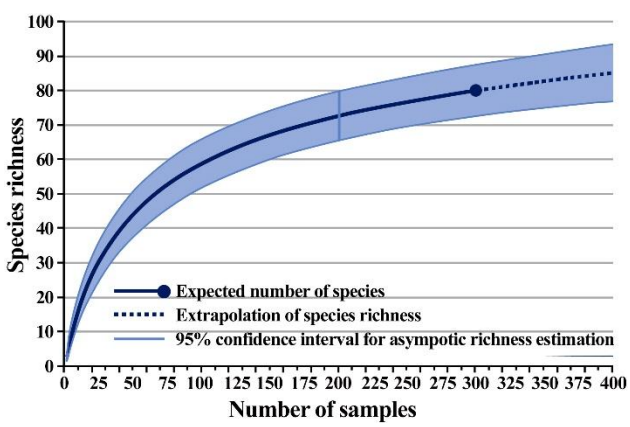

Fig. 3. Species accumulation curves using extrapolation (dashed curves) with 95 confidence interval for asymptotic species richness estimation in given samples from Takkar Wildlife Sanctuary (Colwell, 2013). Y- axis shows the number of species and X-axis shows the number of samples.

Table 2. List of documented flora, alphabetically arranged with family names and botanical names. IUCN status life span, life form, and habit at Takkar Wildlife Sanctuary, Khairpur.

S.No.	Family	Species	English name	Local name	IUCN status	Life span	Life form	Habit
1.	Acanthaceae	*Blepharis scindica* Stocks ex T. Anders	*Blepharis*	Utangan	NE	Annual	Therophyte	Herb
2.	Aizoaceae	*Zaleya pentandra* (L.) Jeffrey.	African Purslane	Waho	NE	Perennial	Chamaephyte	Herb
3.	Amaranthaceae	*Aerva javanica* (Burm. f.) Juss.	Desert Cotton	Booh	NE	Perennial	Phanerophyte	Herb
4.	Amaranthaceae	*Arthrocnemum indicum* (Willd.) Moq.		Lanno	NE	Perennial	Chamaephyte	Herb
5.	Amaranthaceae	*Haloxylon salicornicum* L.	White Saksaul	Lani	NE	Perennial	Phanerophyte	Shrub
6.	Amaranthaceae	*Haloxylon stocksii* (Boiss.) Hook.f.			NE	Perennial	Phanerophyte	Shrub
7.	Amaranthaceae	*Salsola imbricata* Forssk.		Laano	NE	Perennial	Phanerophyte	Shrub
8.	Amaranthaceae	*Suaeda fruticosa* (L.) Forssk. Ex J.F Gmel	Shrub by sea blite	Lanno	NE	Perennial	Phanerophyte	Shrub
9.	Apocynaceae	*Calotropis procera* (Aiton)W.T,Aiton	Apple of Sodom	AK	NE	Perennial	Phanerophyte	Shrub
10.	Asteraceae	*Inula grantioides* Bioss.		Gandraf	NE	Perennial	Hemicryptophyte	Herb
11.	Asteraceae	*Launaea procumbens* (Roxb) Ramyya & Rajag	Dandelion	Bhattar	NE	Perennial	Hemicryptophyte	Herb
12.	Asteraceae	*Leptadenia pyrotechnica* (Forsk.) Decne.	Broom Brush	Khip	LC	Perennial	Phanerophyte	Shrub
13.	Asteraceae	*Mukia maderaspatana* (L.) M.Roem.	Madars pea pumpkin		NE	Perennial	Hemicryptophyte	Herb
14.	Asteraceae	*Pulicaria boissieri* Hook.f.	Small fleabane	Kolmir	NE	Perennial	Chamaephyte	Herb
15.	Bignoniaceae	*Tecomella undulata* (Sm.) Seem.	Desert Teak	Lohiro	EN	Perennial	Phanerophyte	Tree
16.	Boraginaceae	*Heliotropium crispum* Desf.	Salt heliophyte	Kharsan	NE	Annual	Therophyte	Herb
17.	Boraginaceae	*Heliotropium curassavicum* L.	Salt heliophyte	Kharsan	NE	Perennial	Hemicryptophyte	Herb
18.	Boraginaceae	*Heliotropium strigosum* Wild.	Salt heliophyte	Kharsan	NE	Perennial	Hemicryptophyte	Herb
19.	Brassicaceae	*Farsetia hamiltonii* Royle		Lathi	NE	Annual	Therophyte	Herb
20.	Capparidaceae	*Capparis decidua* (Forssk.) Edgew.	Sodada	Kirar	LC	Perennial	Phanerophyte	Shrub
21.	Cleomaceae	*Cleome brachycarpa* Vahl ex DC.	Black strom	Kano Gah	NE	Annual	Therophyte	Herb
22.	Cleomaceae	*Cleome scaposa* DC.	Black strom	Kano Gah	NE	Annual	Therophyte	Herb
23.	Cleomaceae	*Dipterygium glaucum* Decene.		Phair	NE	Perennial	Chamaephyte	Sub-Shrub
24.	Convolvulaceae	*Convolvulus prostratus* Forssk.		Kirhanj	NE	Perennial	Hemicryptophyte	Herb
25.	Cucurbitaceae	*Citrullus colocynthis* (Linn.)Schrad.	Bitter apple	Trooh	NE	Perennial	Hemicryptophyte	Herb
26.	Cucurbitaceae	*Cucumis melo* L.	Muskmelon	Mitero	NE	Annual	Therophyte	Herb
27.	Cyperaceae	*Cyperus rotundus* L.	Nutgrass	Kabah	LC	Perennial	Cryptophyte	Herb
28.	Euphorbiaceae	*Euphorbia granulata* Forssk.	Asthma plant	Kheer wal	NE	Annual	Therophyte	Herb
29.	Fabaceae	*Alhagi maurorum* Medik.		Kandero	NE	Perennial	Phanerophyte	Herb
30.	Fabaceae	*Argyrolobium roseum* Jaub.		Makhan Booti	NE	Annual	Therophyte	Herb
31.	Fabaceae	*Cassia italica* (Mmill.)Spring.	Senegal Senna	Ghora wal	NE	Perennial	Chamaephyte	Herb
32.	Fabaceae	*Crotalaria burhia* Buch-Ham.ex Benth.	Ethiopian rattlebox	Chag	NE	Perennial	Chamaephyte	Sub-Shrub
33.	Fabaceae	*Indigofera oblongifolia* Forssk.	Nilm	Jhill	LC	Perennial	Chamaephyte	Shrub
34.	Fabaceae	*Prosopis glandulosa* Torr.	Honey Mesquite	Babur	LC	Perennial	Phanerophyte	Tree
35.	Fabaceae	*Prosopis cineraria* (L.) Druce		Kandi	NE	Perennial	Phanerophyte	Tree
36.	Fabaceae	*Prosopis juliflora* (Sw,) DC.	Mesquite	Devi	LC	Perennial	Phanerophyte	Tree
37.	Fabaceae	*Tephrosia uniflora* Pers.	Wild Indigo	Maheero	NE	Annual	Therophyte	Herb
38.	Fabaceae	*Vachellia jacquemontii* (Benth.) Ragup., Seigler, Ebinger & Maslin	Desert Acacia	Banwar	NE	Perennial	Phanerophyte	Tree
39.	Fabaceae	*Vachellia nilotica* (L.) P.J.H.Hurter & Mabb.	Gum Arabic tree	Sindhi Bubur	LC	Perennial	Phanerophyte	Tree
40.	Heliotropiaceae	*Heliotropium europaeum* L.	Turnsole	Khasarn	NE	Annual	Therophyte	Herb

Table 2. (Cont'd.)..

S.No.	Family	Species	English name	Local name	IUCN status	Life span	Life form	Habit
41.	Limeaceae	*Limeum indicum* Stocks.ex T.Anderson		Dhoor Chhapri	NE	Annual	Therophyte	Herb
42.	Limeaceae	*Salvia santolinifolia* Boiss.		Shwanko	NE	Annual	Therophyte	Herb
43.	Malvaceae	*Corchorus depressus* (L.) C. Chr	Mountain Jute	Mundheri	NE	Perennial	Chamaephyte	Herb
44.	Menispermaceae	*Cocculus pendulus* (J.R. & G. forst.) Deils	Abuta imene	Fareed Booti	NE	Perennial	Chamaephyte	Climber
45.	Molluginaceae	*Glinus lotoides* L.		Kotak	LC	Annual	Therophyte	Herb
46.	Molluginaceae	*Mollugo cerviana* Linn.		Hazar dani	NE	Annual	Therophyte	Herb
47.	Neuradaceae	*Neurada procumbens* L.		Chhapri	NE	Annual	Therophyte	Herb
48.	Nyctaginaceae	*Boerhavia procumbens* Banks ex Roxb.	Red Spiderling	Dakhri	NE	Perennial	Chamaephyte	Herb
49.	Orobanchaceae	*Cistanche tubulosa* (Schrenk) Hook.f.	Desert hyacinth		NE	Annual	Therophyte	Herb
50.	Plantaginaceae	*Schweinfurthia papilionacea* (Burm. f.) Boiss.		Akri/Paneer- wal	NE	Annual	Therophyte	Herb
51.	Poaceae	*Aristida funiculata* Trin. & Rupr.	Wild Grass	Lumb Gaah	NE	Annual	Therophyte	Grass
52.	Poaceae	*Aristida adscensionis* L.	Six weeks triple awn	Lumb Gaah	NE	Annual	Therophyte	Grass
53.	Poaceae	*Cenchrus ciliaris* Roxb.	Buffel grass	Bhourt	LC	Annual	Therophyte	Grass
54.	Poaceae	*Cenchrus* spp.				Annual	Therophyte	Grass
55.	Poaceae	*Chrysopogon aucheri* (Bioss.) Stapf.	Gold -whiskered Barbet	Khavi	NE	Perennial	Hemicryptophyte	Herb
56.	Poaceae	*Cymbopogon jwarancusa* (Jones) Schult.	Common scented grass	Katan	NE	Perennial	Hemicryptophyte	Grass
57.	Poaceae	*Cynodon dactylon* (L.) Pers.	Bermuda Grass	Chhabar	NE	Perennial	Hemicryptophyte	Grass
58.	Poaceae	*Desmostachya bipinnata* (L.) Stapf.	Halfa grass	Drabh	LC	Perennial	Hemicryptophyte	Grass
59.	Poaceae	*Dichanthium annulatum* (Forssk.) Stapf	Kleberg's bluestem	Palwan	NE	Perennial	Hemicryptophyte	Grass
60.	Poaceae	*Echinochloa colona* (L.) Link.	Junglerice	Sanwak	LC	Annual	Therophyte	Grass
61.	Poaceae	*Eragrostis minor* Host	Gopher tail lover grass	Dhamaaho	NE	Annual	Therophyte	Grass
62.	Poaceae	*Lasiurus scindicus* Hern.	Grass	Booro	NE	Perennial	Hemicryptophyte	Grass
63.	Poaceae	*Ochthochloa compressa* (Forssk.) Hilu.	Fodder Grass	Ghander	NE	Perennial	Hemicryptophyte	Grass
64.	Poaceae	*Saccharum spontaneum* L.			NE	Perennial	Geophyte	Grass
65.	Polygonaceae	*Calligonum polygonoides* L.		Phoog	NE	Perennial	Phanerophyte	Shrub
66.	Polygonaceae	*Polygonum plebeium* R. Br.	Small knotweed	Khowar	NE	Annual	Therophyte	Herb
67.	Portulaceae	*Portulaca oleaceae* L.	Common Purslane	Lunak/Kulfa	LC	Annual	Therophyte	Herb
68.	Rhamnaceae	*Ziziphus nummularia* (Burm.f.) Wt. & A.	Zizphus/Jujubi	Jhanghli Ber	NE	Perennial	Phanerophyte	Shrub
69.	Salvadoraceae	*Salvadora oleoides* Decene	Salvadora	Jar/Peroon	DD	Perennial	Phanerophyte	Tree
70.	Scrophulariaceae	*Anticharis glandulosa* Asch		Gaamesh	NE	Annual	Therophyte	Herb
71.	Solanaceae	*Solanum surattense* Brum.f.		Kanderi wal	NE	Perennial	Hemicryptophyte	Herb
72.	Tamaricaeae	*Tamarix aphylla* (L.) Karst	Athel	Lao	NE	Perennial	Phanerophyte	Tree
73.	Tamaricaeae	*Tamarix indica* Wild.	Athel	Lai	NE	Perennial	Phanerophyte	Shrub
74.	Utriaceae	*Forsskaolea tenacissima* L.		Luchkano	NE	Perennial	Chamaeophyte	Herb
76.	Zygophyllaceae	*Fagonia bruguieri* DC.		Drhamaho	NE	Perennial	Hemicryptophyte	Herb
75.	Zygophyllaceae	*Fagonia cretica* L.		Drhamaho	NE	Perennial	Chamaephyte	Herb
77.	Zygophyllaceae	*Fagonia indica* Burm.f.	Prickly clover	Dhamaaho	NE	Annual	Therophyte	Herb
78.	Zygophyllaceae	*Seetzenia lanata* (Willd.) Bullock			NE	Annual	Therophyte	Herb
79.	Zygophyllaceae	*Tribulus longipetalus* Viv.	Puncture Vine	Bakhro/Bhurt	NE	Annual	Therophyte	Herb
80.	Zygophyllaceae	*Tribulus terrestris* L.	Puncture Vine	Bakhro	LC	Annual	Therophyte	Herb
81.	Zygophyllaceae	*Zygophyllum simplex* L.	Caper-bean	Pat-Lani	NE	Annual	Therophyte	Herb

Table 3. Morisita-Horn similarity index, Similarity, the sites with more than 50% similarity in plant community structure are highlighted green.

	Site-2	Site-3	Site-4	Site-5	Site-6	Site-7	Site-8	Site-9	Site-10	Site-11	Site-12	Site-13	Site-14	Site-15	Site-16	Site-17	Site-18	Site-19	Site-20	Site-21	Site-22	Site-23	Site-24	Site-25	Site-26	Site-27	Site-28	Site-29	Site-30
Site-1	0.33	0.15	0.04	0.21	0.19	0.45	0.11	0.28	0.00	0.21	0.00	0.09	0.07	0.03	0.00	0.00	0.00	0.00	0.02	0.09	0.00	0.17	0.00	0.00	0.34	0.24	0.00	0.23	0.51
Site-2		0.14	0.11	0.24	0.06	0.68	0.07	0.07	0.00	0.00	0.04	0.23	0.04	0.01	0.01	0.01	0.00	0.00	0.05	0.01	0.00	0.05	0.00	0.01	0.17	0.15	0.00	0.95	0.25
Site-3			0.05	0.90	0.11	0.29	0.56	0.10	0.00	0.37	0.00	0.44	0.28	0.14	0.40	0.27	0.70	0.29	0.68	0.10	0.14	0.18	0.00	0.00	0.21	0.17	0.00	0.10	0.29
Site-4				0.25	0.84	0.09	0.01	0.01	0.00	0.01	0.00	0.07	0.39	0.50	0.24	0.00	0.00	0.60	0.02	0.01	0.86	0.28	0.00	0.00	0.03	0.03	0.00	0.11	0.05
Site-5					0.30	0.35	0.60	0.10	0.00	0.41	0.00	0.25	0.16	0.15	0.45	0.01	0.73	0.21	0.72	0.02	0.22	0.15	0.00	0.00	0.23	0.18	0.00	0.19	0.31
Site-6						0.19	0.06	0.06	0.00	0.13	0.00	0.06	0.47	0.52	0.25	0.00	0.00	0.57	0.01	0.04	0.79	0.35	0.00	0.00	0.19	0.14	0.00	0.03	0.24
Site-7							0.24	0.27	0.00	0.00	0.01	0.16	0.07	0.02	0.01	0.00	0.00	0.00	0.02	0.03	0.01	0.09	0.00	0.10	0.59	0.55	0.00	0.56	0.82
Site-8								0.09	0.00	0.24	0.02	0.21	0.05	0.04	0.24	0.00	0.60	0.00	0.59	0.10	0.00	0.05	0.00	0.03	0.19	0.16	0.00	0.03	0.26
Site-9									0.00	0.00	0.00	0.04	0.04	0.01	0.04	0.00	0.00	0.04	0.01	0.00	0.01	0.17	0.00	0.00	0.20	0.16	0.00	0.03	0.32
Site-10										0.00	0.18	0.04	0.04	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.10	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Site-11											0.00	0.05	0.06	0.02	0.07	0.00	0.36	0.00	0.34	0.05	0.00	0.00	0.00	0.00	0.09	0.03	0.00	0.00	0.08
Site-12												0.02	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.06	0.26	0.12	0.00	0.00	0.17	0.00	0.00
Site-13													0.72	0.52	0.42	0.61	0.19	0.63	0.20	0.40	0.33	0.49	0.03	0.00	0.04	0.03	0.03	0.20	0.05
Site-14														0.58	0.29	0.59	0.03	0.86	0.03	0.39	0.69	0.58	0.01	0.04	0.08	0.07	0.04	0.02	0.07
Site-15															0.24	0.30	0.02	0.63	0.02	0.22	0.65	0.50	0.02	0.00	0.01	0.01	0.02	0.00	0.02
Site-16																0.11	0.26	0.44	0.27	0.16	0.31	0.28	0.02	0.00	0.00	0.00	0.00	0.01	0.00
Site-17																	0.00	0.63	0.00	0.21	0.33	0.26	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Site-18																		0.01	0.76	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Site-19																			0.01	0.24	0.86	0.53	0.00	0.02	0.01	0.02	0.00	0.00	0.00
Site-20																				0.05	0.01	0.04	0.04	0.00	0.00	0.00	0.02	0.04	0.00
Site-21																					0.15	0.27	0.02	0.27	0.14	0.25	0.07	0.00	0.02
Site-22																						0.47	0.00	0.06	0.03	0.06	0.00	0.00	0.00
Site-23																							0.13	0.04	0.11	0.04	0.09	0.04	0.13
Site-24																								0.06	0.00	0.00	0.00	0.00	0.00
Site-25																									0.56	0.65	0.00	0.00	0.00
Site-26																										0.70	0.00	0.08	0.64
Site-27																											0.54	0.08	0.54
Site-28																												0.00	0.06
Site-29																													0.12

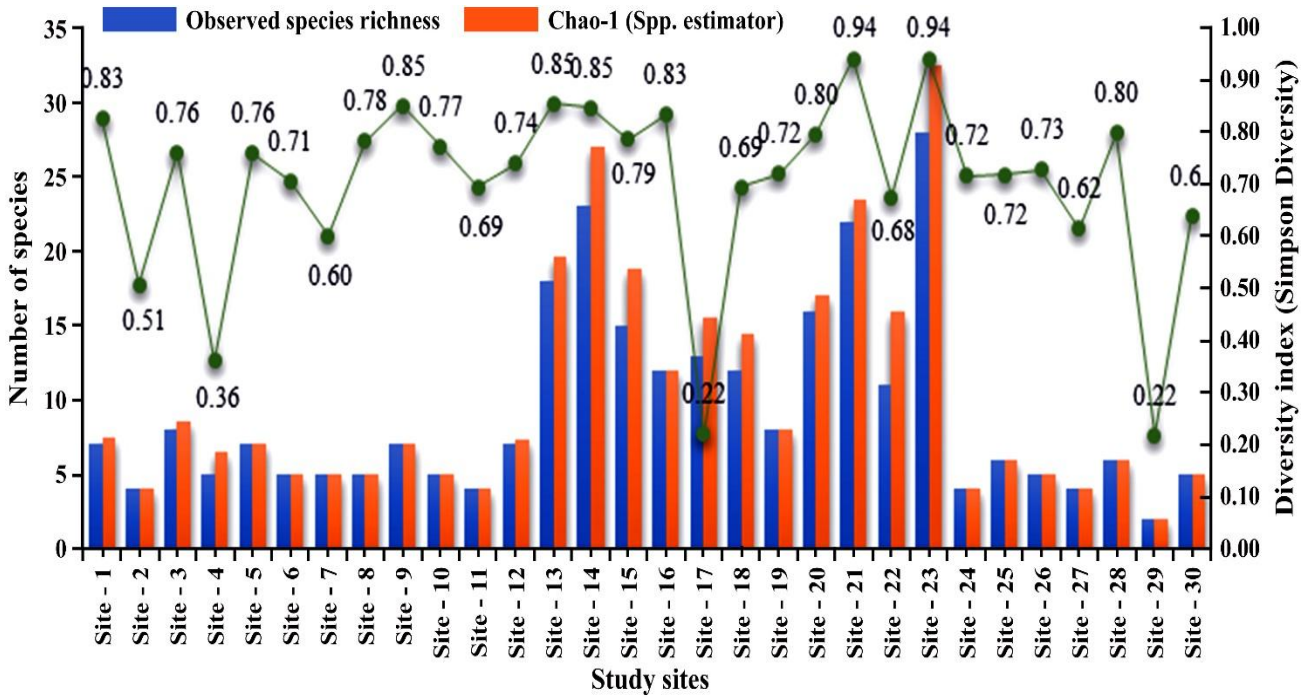

Fig. 4. Species richness and diversity of species at various study sites at Takkar Wildlife Sanctuary.

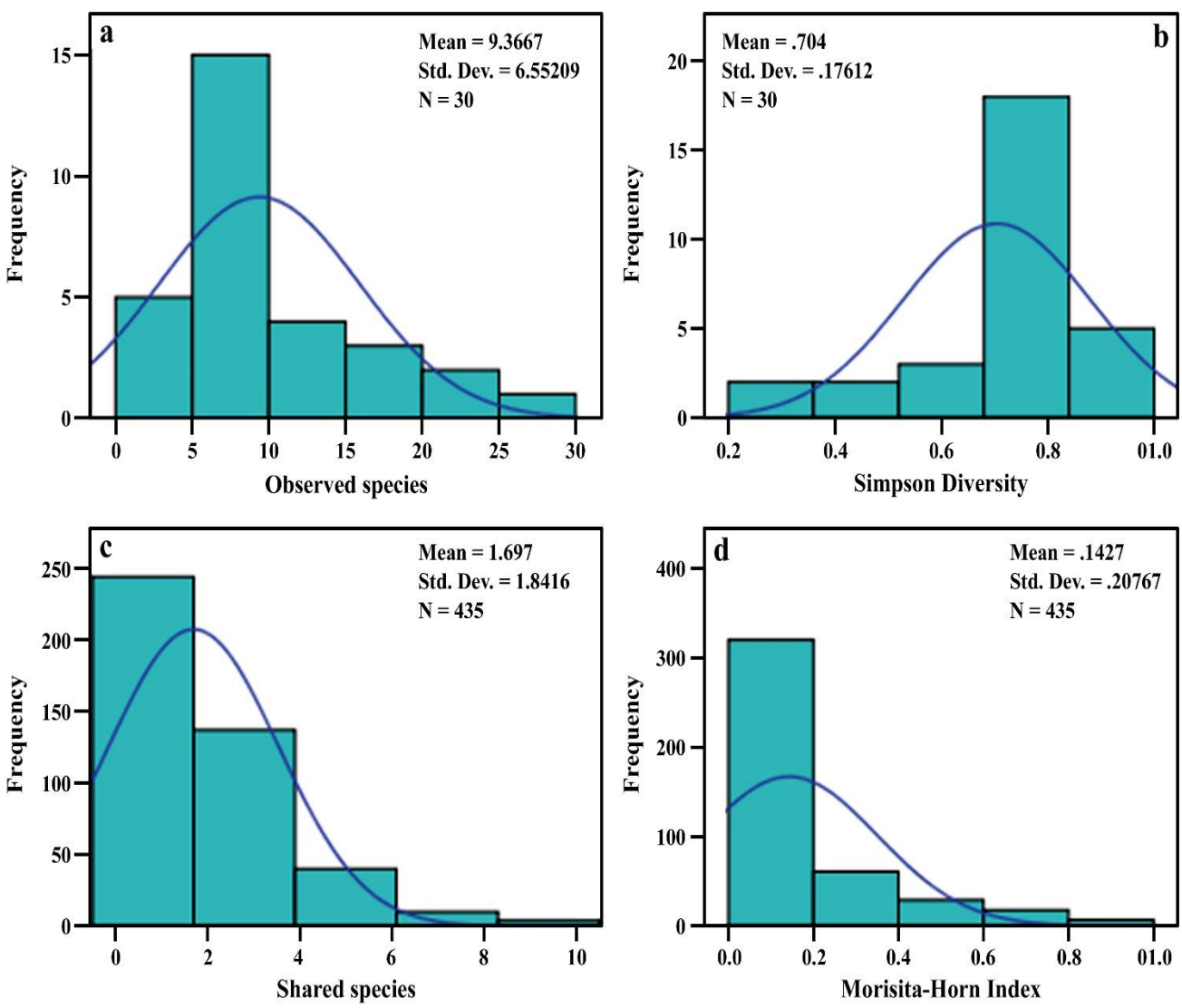

Fig. 5. Frequency distribution of community parameters: a, Observed species; b, Simpsons diversity; c, Shared species; d, Morista-Horn index.

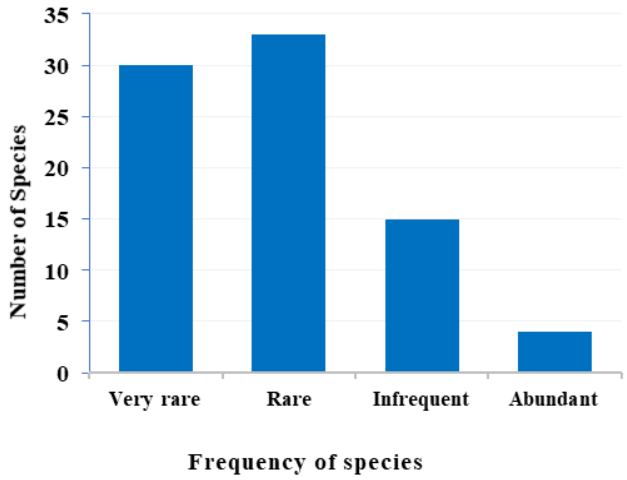

Fig. 6. Frequency of species at Takkar Wildlife Sanctuary Khairpur District.

Based on the frequency and density, *Aerva javanica*, *Anticharis glandulosa*, *Aristida adscensionis*, *Aristida funiculata, Calotropis procera, Capparis decidua, Euphorbia granulata, Fagonia indica, Haloxylon salicornicum, Prosopis juliflora* and *Tephrosia uniflora* were the core species of the habitat (Table 4). Four species - *Haloxylon salicornicum* (Amaranthaceae), *Aristida adscensionis* (Poaceae), *Prosopis juliflora* (Fabaceae), and *Capparis decidua* (Capparidaceae) - were recorded as abundant (Fig. 6). Whereas thirty-three species were classified as rare, thirty as very rare, and fifteen as infrequent. The plant species with the highest relative density include *Tephrosia uniflora, Haloxylon salicornicum, Fagonia indica, Aristida adscensionis, Ochthochloa compressa, Prosopis juliflora, Ziziphus nummularia, Aerva javanica, Aristida funiculata,* and *Anticharis glandulosa* (Table 4).

Life span and habit of flora: The flora in the Takkar region was predominantly composed of herbs, which make up approximately 56.7% of the overall floristic composition. This was followed by shrubs, representing 13.5% (11 spp.), and trees, contributing 9.8% (8 spp.). Grasses accounted for 16%, and climbers contributed one species (Fig. 7a). In terms of lifespan, over half (61.7%) of the plant community was identified as perennials, while the remaining 38.2% comprised of annuals (Fig. 7b). The perennial plant community was primarily composed of shrubs and trees. The vegetation in the study area, as illustrated by the biological spectrum, demonstrated a predominance of therophytes, with 31 plant species contributing to 38.2% of the total species. This was followed by phanerophytes at 24.6% and hemicryptophyte at 19.7% (Fig. 7c).

Species classification: The TWINSPAN analysis divided the plots into two primary groups at the first level of classification, consisting of 10 and 20 plots, respectively (Fig. 8). This initial division, with an eigenvalue of 0.558, effectively separated the plots from the water catchment area and dry stream bed. The indicator species for the left-handed group included *Haloxylon stocksii, Tribulus terrestris, Aristida funiculata, Ochthochloa compressa, Crotalaria burhia,* and *Fagonia indica,* while *Crotalaria burhia* served as the sole indicator species for the right-handed group.

In total, the TWINSPAN analysis categorized 80 species into 20 groups, with 19 species located on the right-hand side (RHS) and 61 species on the left-hand side (LHS) (Fig. 9). At the first level of classification, which yielded an eigenvalue of 0.747, two species - *Cucumis melo* and *Aerva javanica* - were identified in the RHS cluster, while four species - *Schweinfurthia papilionacea, Suaeda fruticosa, Corchorus depressus,* and *Vachellia jacquemontii*-were found in the LHS cluster. Notably, these six species did not cluster with any other species, indicating their unique adaptability to the various microclimatic conditions present in Takkar Wildlife Sanctuary.

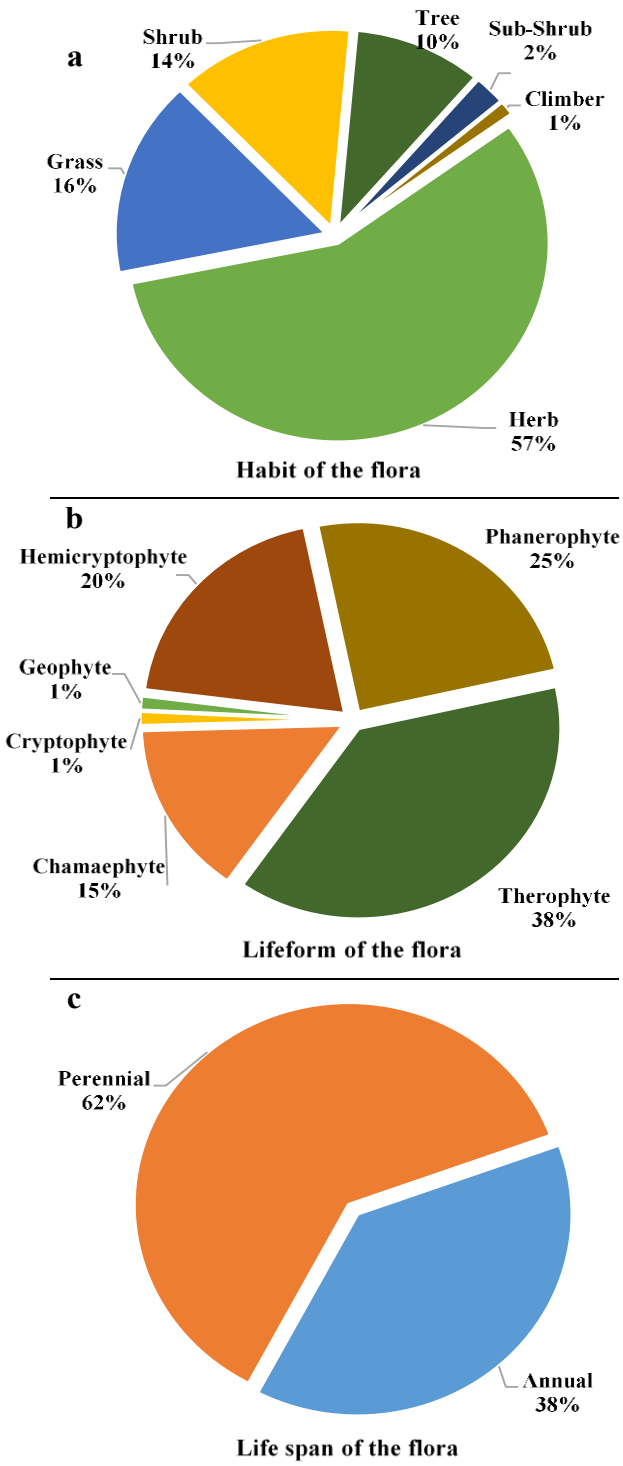

Fig. 7. Physiognomic characteristics of the vegetation at Takkar Wildlife Sanctuary: a, Habit; b, Life form; c, Life span of the flora.

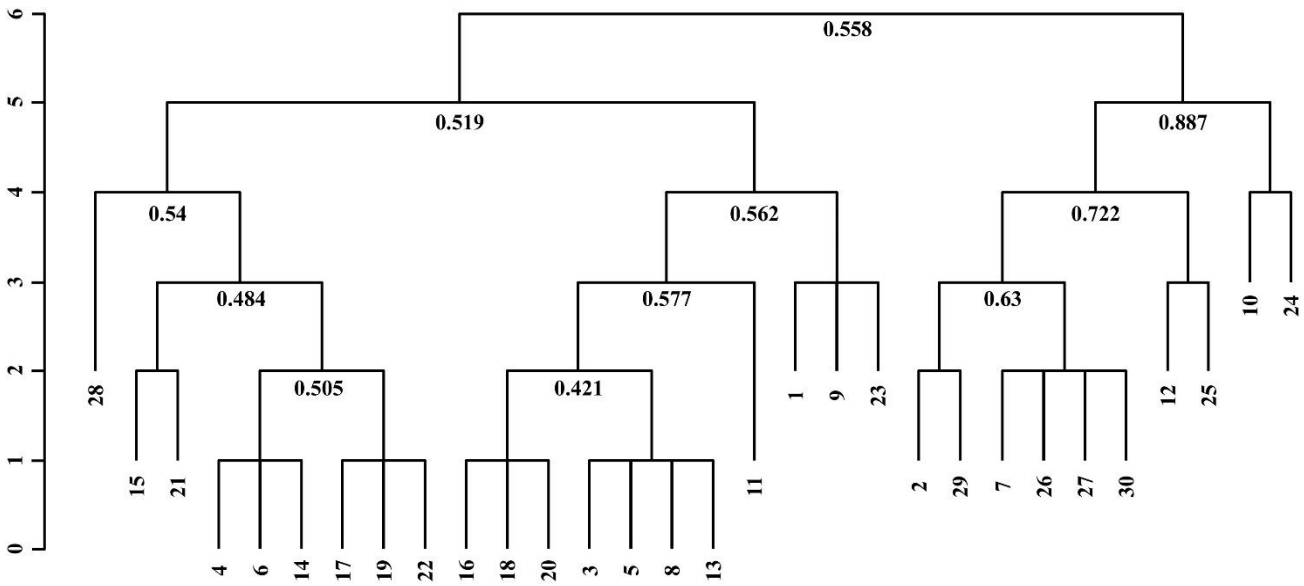

Fig. 8. Classification of study sites by Twinspan. Decimal number at each node represent the Eigenvalue (heterogeneity) of at the given level of cluster.

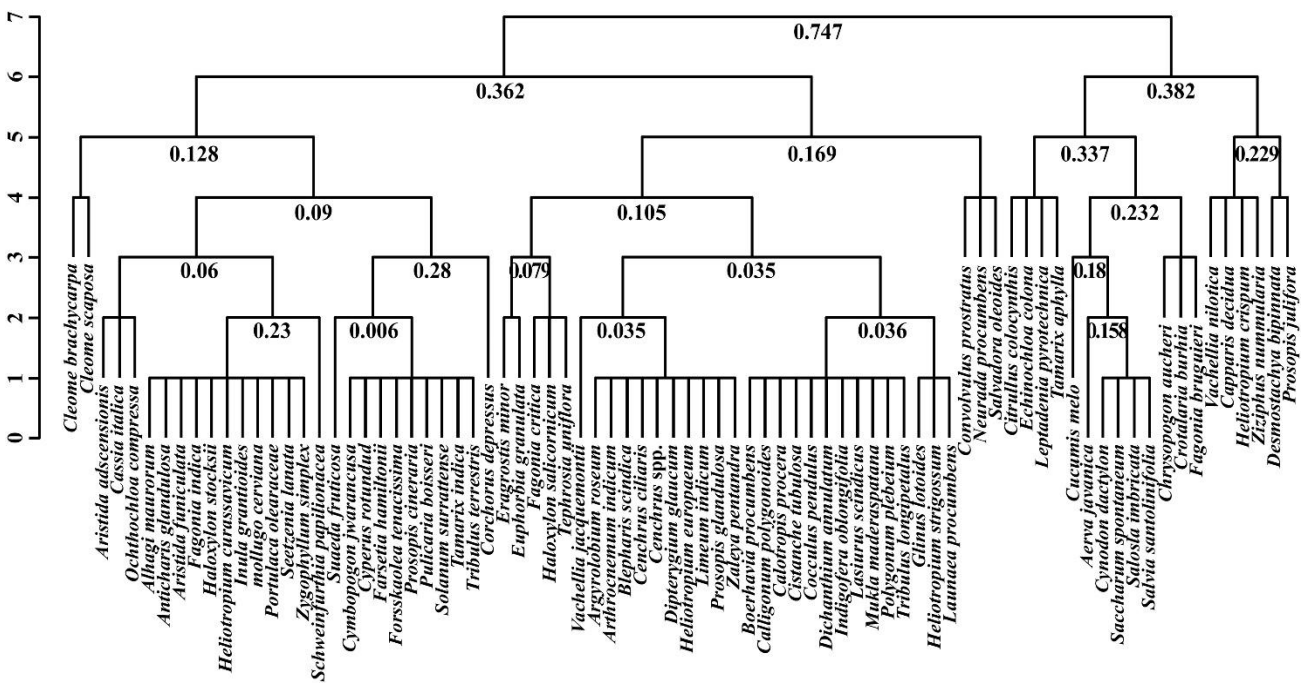

Fig. 9. Twinspan classification of species. Decimal number at each node represent the Eigenvalue (heterogeneity) of at the given level of cluster.

IUCN Status of documented flora: Verification of all reported species was conducted using the IUCN Red List categories (Anon., 2025). Among the 81 species recorded, 16 were classified as Least Concern (LC), while one species, *Tecomella undulata*, was categorized as Endangered (EN). Additionally, *Salvadora oleoides* was classified as Data Deficient (DD), and the remaining species fell under the Not Evaluated (NE) category (Table 2).

Discussions

Takkar Wildlife Sanctuary features a distinctive topography characterized by steep gentle slopes, sand dunes, and sandy soil interspersed with loose rocks and clay, exhibiting moderate calcareous properties. The soil in this habitat is notably deficient in organic matter. Due to the prevalence of harsh environmental conditions, the vegetation has adapted uniquely, comprising species of significant ecological importance. The sparse vegetation of the Takkar Wildlife Sanctuary is predominantly made up of xerophytic plant species. Several environmental factors, including limited water availability, highly variable seasonal temperatures, low soil fertility, and moisture fluctuations, contribute to this particular vegetation pattern. The region is largely dominated by scattered thorny or prickly shrubs and perennial herbs that possess drought-tolerant characteristics. Most of the herbaceous plants are ephemeral, flourishing only during specific times of the year. These plants complete their life cycle within a few weeks, and the areas where their seeds are shaded often appear devoid of vegetation. Despite their slow growth rates, these species can thrive under favorable conditions, producing substantial biomass that can be utilized by cattle.

Table 4. Phytosociological analysis and structure show plant families with frequency, relative Frequency, density, and relative density of documented plant species at Takkar wildlife sanctuary.

Species	D	RD	RF	F
Aerva javanica	0.2166	0.0290	0.025	60
Alhagi maurorum	0.03	0.0040	0.0041	10
Anticharis glandulosa	0.1466	0.0196	0.0194	40
Argyrolobium roseum	0.0033	0.0004	0.0013	30
Aristida adscensionis	0.5966	0.0799	0.0347	80
Aristida funiculate	0.1866	0.0250	0.0236	50
Arthrocnemum indicum	0.0033	0.0004	0.00138	30
Blepharis scindica	0.0033	0.0004	0.00138	30
Boerhavia procumbens	0.0033	0.0004	0.00138	30
Calligonum polygonoides	0.03	0.0040	0.0055	10
Calotropis procera	0.08	0.0107	0.0222	50
Capparis decidua	0.0966	0.0129	0.0291	70
Cassia italica	0.0133	0.0017	0.0055	10
Cenchrus ciliaris	0.0066	0.0008	0.00138	30
Cenchrus spp.	0.0033	0.0004	0.0013	30
Chrysopogon aucheri	0.0233	0.0031	0.0055	10
Cistanche tubulosa	0.01	0.0013	0.0013	30
Citrullus colocynthis	0.02	0.00267	0.0055	10
Cleome brachycarpa	0.0166	0.0022	0.00694	10
Cleome scaposa	0.0966	0.0129	0.01944	40
Cocculus pendulus	0.0133	0.0017	0.0041	10
Convolvulus prostratus	0.0366	0.0049	0.009	20
Corchorus depressus	0.09	0.0120	0.0194	40
Crotalaria burhia	0.076	0.0102	0.0166	40
Cucumis melo	0.01	0.0013	0.0027	60
Cymbopogon jwarancusa	0.0066	0.0008	0.0027	60
Cynodon dactylon	0.07	0.009	0.00694	10
Cyperus rotundus	0.006	0.0008	0.00138	30
Desmostachya bipinnata	0.06	0.008	0.0083	20
Dichanthium annulatum	0.01	0.0013	0.0013	30
Dipterygium glaucum	0.04	0.0053	0.01527	30
Echinochloa colona	0.00667	0.0008	0.00277	60
Ephedra ciliata	0	0	0.0013	30
Eragrostis minor	0.146	0.019	0.0263	60
Euphorbia granulata	0.12	0.016	0.022	50
Fagonia critica	0.1466	0.0196	0.0111	20
Fagonia bruguieri	0.0466	0.0062	0.011	20
Fagonia indica	0.71	0.095	0.066	60
Farsetia hamiltonii	0.0233	0.0031	0.0055	10
Forsskaolea tenacissima	0.02	0.0026	0.005	30
Glinus lotoides	0.0233	0.0031	0.0041	10

Table 4. (Cont'd.).

Species	D	RD	RF	F
Haloxylon salicornicum	0.81	0.1085	0.0777	80
Haloxylon stocksii	0.046	0.0062	0.0111	20
Heliotropium crispum	0.0366	0.0049	0.0097	20
Heliotropium curassavicum	0.0033	0.0004	0.0013	30
Heliotropium europaeum	0.0333	0.0044	0.0069	10
Heliotropium strigossum	0.0166	0.002	0.004	10
Indigofera oblongifolia	0.0033	0.000	0.0013	30
Iphiona grantioides	0.0466	0.0062	0.0111	20
Lasiurus scindicus	0.0066	0.0008	0.0013	30
Launaea procumbens	0.02	0.002	0.0055	10
Leptadenia pyrotechnica	0.07	0.0093	0.01666	40
Limeum indicum	0.05333	0.007	0.0125	30
Mollugo cerviana	0.0166	0.0022	0.00416	10
Mukia maderaspatana	0.0166	0.0022	0.0055	10
Neurada procumbens	0.05	0.0066	0.0111	20
Ochthochloa compressa	0.41	0.0549	0.04166	10
Polygonum plebeium	0.006	0.000	0.0013	30
Portulaca olearaceae	0.003	0.0004	0.00138	30
Prosopis cineraria	0.0066	0.000	0.00416	10
Prosopis glandulosa	0.0033	0.0004	0.0013	30
Prosopis juliflora	0.3733	0.0500	0.0736	70
Pulicaria boisseri	0.0066	0.0008	0.0013	30
Saccharum spontaneum	0.0333	0.0044	0.0055	10
Salsola imbricata	0.0966	0.0129	0.0138	30
Salvadora oleoides	0.03	0.004	0.0125	30
Salvia santolinifolia	0.0233	0.0031	0.0027	60
Schweinfurthia papilionacea	0.0333	0.0044	0.011	20
Seetzenia lanata	0.0133	0.0017	0.004	10
Solanum surattense	0.003	0.000	0.0013	30
Stipagrostis plumosa	0	0	0.0013	30
Suaeda fruticosa	0.03	0.0040	0.0041	10
Tamarix aphylla	0.0166	0.0022	0.0027	60
Tamarix indica	0.0033	0.0004	0.0013	30
Tephrosia uniflora	1.4366	0.192	0.068	60
Tribulus longipetalus	0.0233	0.0031	0.0027	60
Tribulus terrestris	0.026	0.0035	0.0083	20
Vachellia jacquemontii	0.0166	0.0022	0.0069	60
Vachellia nilotica	0.0133	0.0017	0.0041	10
Zaleya pentandra	0.0066	0.000	0.0027	60
Ziziphus nummularia	0.2333	0.031	0.0611	40
Zygophyllum simplex	0.1266	0.0169	0.0152	30

Whereas D = Density, RD = Relative density RD = Relative frequency and R = Frequency

Takkar Wildlife Sanctuary is home to a diverse array of species, which can be attributed to the harsh environmental conditions prevalent in the area. The number of species identified in this study is comparable to those found in other habitats within Sindh Province (Perveen and Hussain, 2007; Qureshi and Bhatti, 2005; Qureshi and Ahmad, 2010; Muhammad *et al*., 2016; Saand *et al*., 2019; Sirohi *et al*., 2019). The species accumulation curves suggest that an adequate number of samples have been collected to comprehensively document the floristic composition of the habitat. However, some species remain unrecognized during vegetation sampling, potentially due to sparse vegetation and the presence of rare species in the study area (Shaheen *et al*., 2014).

The predominantly hilly and desert regions of Sindh, Pakistan, are characterized by scattered vegetation and the stunted growth of thorny or prickly shrubs and perennial herbs (Qureshi and Bhatti, 2010; Perveen and Hussain, 2007; Miller *et al*., 2005; Shaheen *et al*., 2014). This situation is the result of deforestation, soil depletion, low precipitation, increased grazing pressure, and mining activities (Yan *et al.,* 2022). Habitats experiencing water stress typically exhibit limited plant species diversity, a pattern that was also observed at Takkar Wildlife Sanctuary. It is possible that the species richness of thirty distinct habitats within the same location may vary significantly from one another (Rodrigue *et al*., 2018). This variability is attributed to the topographical differences between these sites, as well as the diverse microhabitats present within each area (Wani *et al.,* 2023).

A biological assessment, including metrics such as species richness and floristic diversity, is a vital component for understanding the ecology of the Takkar Wildlife Sanctuary and its functions within the ecosystem (Ali *et al*., 2016). Species diversity is positively correlated with habitat area. The Poaceae and Fabaceae families were identified as the most prevalent in the Takkar habitat. Many plant species within these families are adapted to xeric conditions. The dominance of these families has also been documented in desert and mountainous regions of Pakistan, Saudi Arabia, and India (Qureshi & Bhatti, 2010; Shaheen *et al*., 2014; Saand *et al*., 2019). Poaceae and Fabaceae rank as the third and fifth largest plant families, respectively, with their species distributed globally and thriving in a variety of habitats. Members of the Poaceae family, such as *Aristida adscensionis, Ochthochloa compressa, Lasiurus scindicus, Cenchrus ciliaris, Cymbopogon jwarancusa, Stipagrostis plumosa, Dichanthium annulatum,* and *Eragrostis minor*, possess fibrous root systems that enable them to anchor in rocky creeks and flat habitats with limited water availability. Similarly, members of the Fabaceae family, including *Prosopis juliflora, Vachellia nilotica* (synonym: *Acacia nilotica*)*, Vachellia jacquemontii* (synonym: *Acacia jacquemontii*)*, Cassia italica, Crotalaria burhia,* and *Indigofera oblongifolia*, are xerophytic in nature and are well-suited to survival in desert environments (Zarif *et al*., 2018). The same species have also been recorded in arid areas of Sind. The first floristic inventory survey of the Thar Desert, conducted by Chauudri & Chatter (1966), reported 122 plant species. This high number of species may be attributed to the presence of a diverse range of microhabitats. Additionally, it was found that the families Amaranthaceae, Cucurbitaceae, and Euphorbiaceae predominated in the Thar Desert (Qureshi & Ahmad, 2010).

The classification of life forms is a significant aspect of plant physiognomy that influences the harmony between plants and their environment. This study area was predominantly characterized by therophytes and phanerophytes in terms of life form. Similar observations have been reported in various regions of the country (Perveen & Hussain, 2007; Qureshi & Bhatti, 2010; Sirohi *et al*., 2019). The predominance of therophytes over other life forms may be a response to warm, dry weather, topographic variation, and human disturbances (Khan *et al*., 2012). Additionally, these plants possess the capability to adapt to xeric environments through various mechanisms. Such pants have dormant buds under unfavorable conditions, e.g. chamaephytes featuring perennating buds situated less than 25 centimeters above the ground to minimize exposure to wind. These adaptations enable them to thrive in xeric habitats. Therophytes, on the other hand, are predominantly annuals or ephemerals with short life cycles, typically blooming during the rainy season. In arid regions, rainfall is the most critical factor for plant growth (Arshad *et al*., 2008). Our research findings indicate that perennials (61.7%) were more dominant than annuals (38.2%). The presence of perennials may suggest that these species are capable of withstanding harsh climatic conditions or are able to access sufficient moisture following monsoon rains for an extended period (Sirohi *et al*., 2019). In contrast, the presence of annuals may be a result of the monsoon, which enhances the growth of annual herbaceous plants.

The TWINSPAN analysis underscores the intricate and diverse nature of the plant communities within the Takkar Wildlife Sanctuary. This classification has revealed significant patterns in species distribution and association. Notably, some species demonstrated vast adaptability and did not cluster with others. Specifically, *Schweinfurthia papilionacea, Suaeda fruticosa, Corchorus depressus, Vachellia jacquemontii, Cucumis melo,* and *Aerva javanica* each formed solitary groups. This solitary clustering suggests that these species possess a greater adaptability to the diverse microclimatic conditions of the Takkar habitat, enabling them to thrive independently of other species. The largest cluster, comprising 10 species, predominantly consisted of herbs, highlighting their significant presence within this ecosystem. This clustering reinforces the ecological importance and dominance of herbs in the Takkar Wildlife Sanctuary, likely owing to their adaptability to arid conditions and their role in maintaining soil stability and providing habitats for other organisms.

A significant number of reported species have not been evaluated (NE category). However, various plant biologists from Pakistan and other countries have assessed these species as vulnerable or endangered at a regional level. Endangered species play a crucial role in maintaining ecosystem functions; therefore, they should not be overlooked. Many plants found in arid regions are overexploited by local communities, leading to their extinction (Milton & Dean, 2010). This study reported the presence of *Tecomella undulata* in the study area. The Taxon, commonly known as desert teak, has been identified as a native tree of the region and classified as endangered (EN). This plant thrives in dry and semi-arid climates. It is typically found in flat areas but can also grow on gentle slopes and ravines. The species is capable of growing on stabilized sand dunes and can withstand extreme temperatures and low rainfall; the Thar Desert is reported to host the largest population of this species (Kalia *et al*., 2014).

Only two specimens of *Tecomella undulata* were observed in a dry streambed near Dadan jo Dero. One tree has a large trunk and appears to be nearly a century old, according to local residents. This species seems to have once thrived in Takkar Wildlife; one individual was reported from the Rohri Hills, located approximately 30 kilometers from this site. This suggests that *Tecomella* was historically present in the area; however, currently, few individuals from this location have been documented. The species is highly sought after for various reasons, including its aesthetic value, medicinal properties, utility in agroforestry, and, most importantly, its high-quality timber and fuelwood (Kalia *et al*., 2014). Consequently, it has been extensively and carelessly exploited. Slow regeneration rates and slow growth further increase its vulnerability to removal from the wild. Extensive grazing activities also pose a significant threat to the survival of young seedlings (Garg & Mittal, 2013). The clearing of land across the range for agricultural and urban purposes has become increasingly common; anthropogenic activities have accelerated desertification, and recurring droughts have been recorded. A lack of awareness about conservation efforts exacerbates this issue.

To inform conservation efforts and management strategies for the species, further research into the scope and severity of the aforementioned threats is required. The predominance of therophytes suggests that the area has experienced high levels of biotic pressure due to deforestation and overgrazing, with many plants being uprooted for firewood and grazed by livestock. Numerous plant species are declining in the area, indicating that special care is needed for their conservation.

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Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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