scientific Reports in life Sciences

Biodiversity Conservation Society

Spatial assessment, distribution patterns, and diversity of selected floral species across arid rangelands

Jawad Ali Akhtar*

Faculty of Agriculture and Environment, The Islamia University of Bahawalpur, Pakistan
*Email: jawadalipro9@gmail.com

ARTICLE INFO

Keywords:

Cholistan Desert
plant diversity
Vascular flora
Spatial distribution
Habitat heterogeneity
Desert ecology

ABSTRACT

Notwithstanding the variability in rainfall, extreme aridity, salinity, and low soil fertility, the Cholistan Rangelands have specialized vegetation. The floristic composition, spatial distribution, habitat association, and diversity of the vascular plants have been studied in the landscape of the Cholistan Rangelands. Sand dunes, sandy plains, shrubland habitats, agricultural ecotones, saline Dahars, drainage channels, toba margins, and other habitats were sampled in the field from March 2025 to January 2026. GPS coordinates were taken and recorded in a GIS, and species were determined by family, growth form, life cycle, and Raunkiaer life form. Fifty-eight species from 19 families were recorded and selected. Asteraceae (15.5%) was the richest family, and Aizoaceae, Capparaceae, and Chenopodiaceae contained six species each (10.3%). The highest number of species (18 species; 31.0%) was found in sand dunes and 10 species in sandy plains. The Shannon diversity at the family level was 2.638, the Simpson diversity was 0.914, and the Pielou evenness was 0.896; the habitat-level values were 1.907, 0.825, and 0.917, respectively. Analyzed distribution patterns suggest that substrate, salinity, moisture availability, and habitat heterogeneity influence vegetation throughout Cholistan. Conservation of representative habitats and maintaining perennial vegetation is thus critical to the maintenance of rangeland biodiversity, ecosystem function, and resilience.

Received: 22 August 2026; revised: 18 September 2026; accepted: 21 September 2026; and published online: 27 September 2026.
How to cite: Akhtar, J. A. (2026). Spatial assessment, distribution patterns, and diversity of selected floral species across arid rangelands, Scientific Reports in Life Sciences, 7(2): 49-76. DOI: https://doi.org/10.5281/zenodo.22981594

Introduction

Some of the most severe terrestrial habitats are arid and hyper-arid environments, where the strong variations in precipitation patterns, extreme temperature fluctuations, nutrient-poor soil and acute water deficiency, plant communities are heavily influenced (Noy-Meir, 1973; Whitford, 2002). Despite these ecological constraints, desert environments support a myriad of highly specialized plant communities, which have different physiological, morphological and ecological responses to drought stress (Larcher, 2003; Ward, 2016). Desert vegetation dynamics are directly responsible for a number of crucial ecosystem functions such as soil stabilization, resistance to wind erosion, nutrient cycling, and the supply of micro-habitats for a variety of arid fauna (Maestre et al., 2016; Berdugo et al., 2020). Vegetation structure and the desert ecosystem in Cholistan continue to change due to anthropogenic activities (Arshad & Akbar, 2002). The ecological base of Cholistan rangelands relies on vegetation, as it sustains livestock utilization, helps control the sand dunes, and supports ecosystem resilience (Arshad & Akbar, 2002). Of these, the Cholistan Desert is one of the most significant BDZs, covering around 26,000 - 40,000 sq. km. in the south of the Province of Punjab (Arshad et al., 2002; Faisal et al., 2025). This area is located on the northwest fringe of the larger Thar Desert, which experiences high climatic variability with irregular monsoonal rainfall, frequent droughts, high summer temperatures, and high P.E.T. (Potential Evapotranspiration) (Arshad & Akbar, 2002; Shamim et al., 2022). The native plant life is largely composed of drought-tolerant xerophytes, psammophytes, salt-tolerant halophytes, and deep-rooted woody perennials that are adapted to arid conditions (Rao and Arshad, 1991; Wariss et al., 2021). The distribution and assembly of desert vegetation are largely controlled by spatial variation in edaphic factors such as soil texture, salinity gradients, topographic relief, and localized grazing pressures (Mueller-Dombois & Ellenberg, 1974; Kent, 2012). Landscape heterogeneity, especially at small scales, can be especially important in desert ecosystems, providing small patches of moisture and/or substrate heterogeneity that can provide important refugia in an otherwise inhospitable landscape (Noy-Meir, 1973; Haider et al., 2022). In the Cholistan landscape, these ecologically divergent habitats are represented by shifting/semi-stabilized sand dunes, low-lying interdunal plains, compacted saline clay depressions (also known as dahars), and temporary catchments of rainwater (tobas) with their different plant functional groups and community composition (Faisal et al., 2025).

The phytosociological studies have shown that vegetation composition differs among the major landscape units of the Cholistan Desert, which are related to differences in soil characteristics, moisture availability and disturbance regimes (Arshad & Akbar, 2002). The vegetation in the Cholistan Desert also offers significant ecological services such as forage production and sand dune stabilization, which is why it is essential to conserve for sustainable management of the desert ecosystem (Akbar et al., 1996; Arshad & Akbar, 2002). Arid ecosystems experience episodic rainfall events that create pulses in resources which drive primary productivity, nutrient cycling, and ecosystem dynamics for short periods of time and have a strong influence on vegetation establishment and community structure (Noy-Meir, 1973; Austin et al., 2004). The use of modern spatial evaluations based on remote sensing indices and Geographic Information Systems (GIS) today offers a solid tool for the identification of micro-habitats of high conservation value. It enables the mapping of distinct phytosociological zones and sustainable rangeland management (Magurran, 2004; Kent, 2012). Moreover, it is essential to define accurate habitat preferences for desert plant communities to predict the response of the movement of desertification boundaries and increasing land-use threats (Sala et al., 2000; Ullah et al., 2023). Spatial heterogeneity, habitat connectivity, and ecological processes in desert ecosystems are addressed in terms of modern landscape ecology (Turner, 2005). Ecological processes at various scales have a significant influence on the composition of species and organization of habitats (Levin, 1992; Turner, 2005). The Raunkiaer life-form system is still used worldwide to assess changing plant functional configurations as a function of environmental stress (Raunkiaer, 1934). The proportion of therophytes is higher in hyper-arid systems because these periods of drought and rain are unpredictable, whereas the chamaephytes, hemicryptophytes and phanerophytes are dependent on permanent structural adaptations to cope with droughts and extreme temperatures (Cain and Castro, 1959; Mueller-Dombois and Ellenberg, 1974). Dryland biodiversity is declining globally due to increased desertification, climate variability, and anthropogenic disturbances. It should be monitored long-term and managed sustainably (Reynolds et al., 2007; Huang et al., 2016). The current anthropogenic impacts on the Cholistan Desert's fragile ecosystem are multifaceted, such as very high levels of overgrazing, habitat fragmentation, widespread groundwater extraction and climatic changes, which are causing rainfall patterns to change (Arshad et al., 2002; Rasheed et al., 2022).

This study aimed to track the distribution of different flora in the arid terrain and their diversity and exact distribution locations. It was used to determine exact locations with the help of GIS and locate them according to their suitability in the landscape. Proper statistical analyses were performed to measure diversity of plant and to know about the description of their sites at where they are found. These distribution patterns improve understanding of plant diversity and habitat associations. It was also important to know about the diversity of the plants and their specific characteristics in contrast to each other.

Materials and methods

Study Area

The study was carried out in the Cholistan Desert, in the Punjab Province of Pakistan (Arshad et al., 2002). The desert area is about 26,000 km² and has an arid to hyper-arid climate, characterized by generally low annual rainfall (below 200 mm) and rainfall mostly during the summer monsoon (July-September) (Arshad et al., 2002). The land forms include active and stabilized sand dunes (Tibas), interdunal sandy plains, saline depressions (Dahars), ephemeral drainage channels (Kas) and rain water harvesting ponds (Tobas) (Arshad & Akbar, 2002). This environmental diversity is responsible for different ecological niches, which in turn affect both the distribution and survival of desert plant communities (Arshad et al., 2002) (Figure 1).

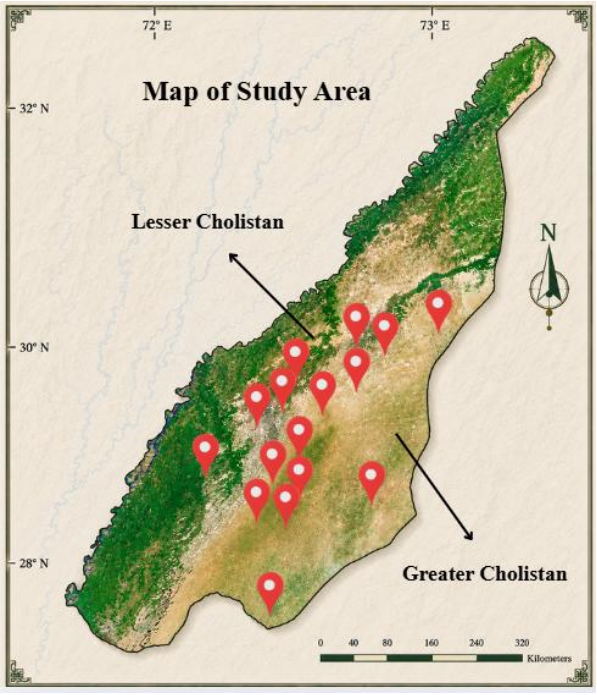

Figure 1. Map of the study area in Punjab, Pakistan, containing locations of all fifty-eight plants where they were located

Vegetation survey and sampling design

The distribution trend, habitat associations, and ecological parameters of representative vascular plant species of Cholistan Rangelands were assessed during the period of March 2025 to January 2026. Surveys were conducted in different seasons, including both ephemeral annuals that grow after rainfall and perennial xerophytes. Representative ecological units, such as active and stabilized dunes, sandy plains, shrublands, saline Dahars, and ephemeral channels, were sampled using a habitat sampling method. Floristic survey procedures were followed in the field at each site (Kent, 2012). Handheld Global Positioning System (GPS) receivers with the World Geodetic System 1984 (WGS84) coordinate reference system were used to locate geographical positions (Table 1).

Plant identification and taxonomic classification

Plant specimens were collected using herbarium procedures, which included pressing, drying, and mounting plant herbarium sheets using standard field and herbarium techniques (Jain and Rao, 1977). Identification of plants was carried out with the help of the floras and botanical literature, including the Annotated Catalogue of the Vascular Plants of West Pakistan and Kashmir (Stewart, 1972) as well as the multi-volume Flora of Pakistan (Ali and Qaiser, 1993–2024). Cross-checking of the scientific nomenclature and recorded local species names was carried out with the latest taxonomic database, namely the World Flora Online (WFO) database (World Flora Online, 2026). Older taxonomic names were updated according to the most recent systems, including the Angiosperm Phylogeny Group IV system (Angiosperm Phylogeny Group, 2016). The perennating buds of the plant life were used to classify them into plant forms, the system proposed by Raunkiaer (1934), according to the position of the perennating buds. The growth habits of plants were described as herb, grass, shrub, subshrub, tree, or climber, and life cycles (annual or perennial) were classified based on the ecological approach to vegetation classification (Mueller-Dombois and Ellenberg, 1974). Different areas were selected so that plants in different areas could be determined,

Habitat classification and spatial distribution

The distribution of plant species was measured using the method of mapping their existence within each of the nine landscape units. GPS was used to locate each species at specific coordinates in the study sites. The whole distribution map was made by measuring longitudes and latitudes using GIS. A species was assigned a principal habitat from the field survey data, soil salinity and

moisture availability, and anthropogenic influences. The desert landscape is a mosaic of ecological conditions with variations in vegetation structure, soil characteristics, and ecosystem resilience. (Bestelmeyer et al., 2009).

Plant height measurement

The vertical distance from the ground to the top of the main vegetative canopy was considered plant height. The height of grasses, herbs, and other short plants was measured directly with a straight measuring rod or measuring tape placed vertically next to the plants. Inflorescences and/or especially projecting branches were not included if they were not intended as the measured trait, but if reproductive height was specifically measured (Cornelissen et al., 2003; Pérez-Harguindeguy et al., 2013). A vertical reference pole of known length was placed next to the main stem and at a roughly equal distance from the observer as the shrub or small tree, for those which could not be measured directly. The height of the plant was then judged against the known length of the pole and the result recorded as the apparent height of the plant. The pole was kept upright, and observations were made at a point from which a clear view of the base of the plant and the tallest part of the crown could be seen. Reference-pole methods are appropriate for trees that are moderately tall, but can produce errors if the pole and tree are not at the same distance from the observer, or if the tree is leaning (Curtis, 2005; Bragg, 2008). A cheap piece of wood was cut to the shape of a hypsometer, following a geometric principle based on similar triangles, for taller people. The instrument included the horizontal arm and vertical arm at right angles and a sighting line. The distance between the tree and the observer was measured horizontally, and the instrument was held at eye level.

The instrument was translated around in a horizontal plane so that the line of sight was parallel to the highest point on the crown. The height of the trees was determined as follows:

$H=D\left(\frac{L}{V}\right)+E$

H is the total height of the tree, D is the horizontal distance between the observer and the base of the tree, V is the vertical dimension of the wooden instrument and L is the horizontal distance of the line of sight of the instrument, and E is the vertical height of visual observation or the instrument above the ground. When both vertical and horizontal arm lengths are the same, the sighting angle is 45 ∘ V/L=1 and the equation reduces to: H=D+E. This equation is valid only if the tree base and observer are near the same ground level and the crown top is vertically overhead the tree base. If the ground has a slope, measure angles to the crown top and tree base and tree

height should be taken by the tangent method: H=D(tanα−tanβ) Here, α is the angle made with the crown top, and β is the angle made with the tree base; both above and below the horizontal are given a positive sign. Similar-triangle and tangent methods are used practically in the field. (Curtis, 2005; Bragg, 2008).

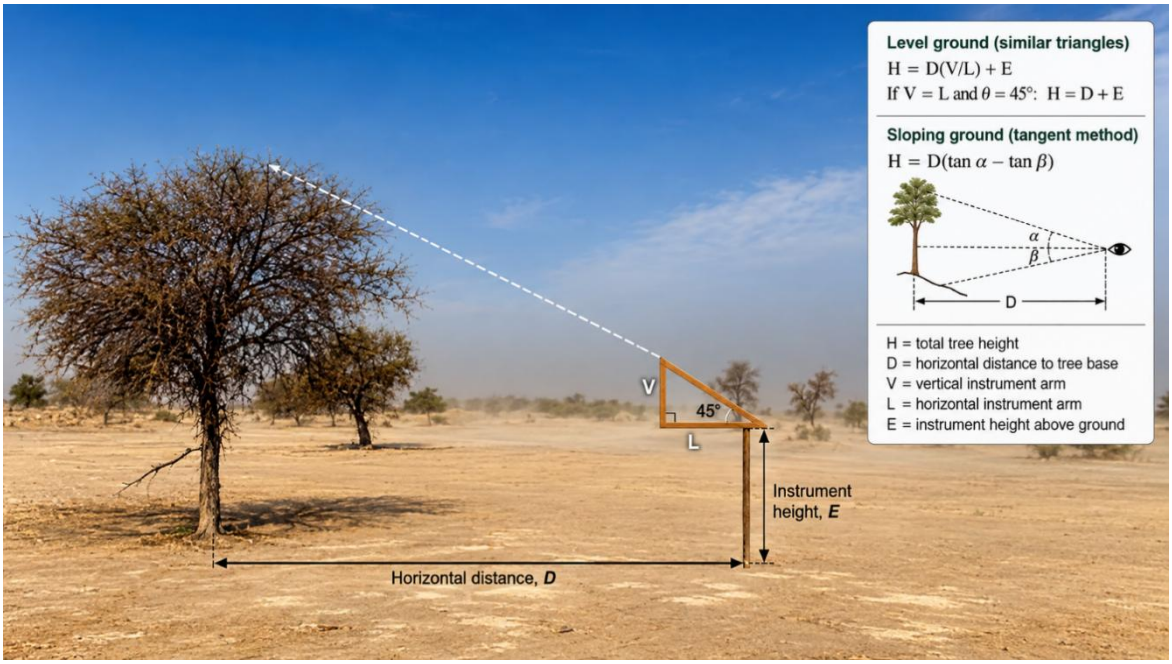

Figure 2. A self-made wooden protector being used to measure tree height

Data analysis

The species recorded were subjected to taxonomic analysis, habitat distribution, life form, growth habit, and life cycle characteristics. Species richness was determined for each species family and habitat type. For calculating the percentage contribution of each component, the following formula was used:

Percentage contribution (%) = (Ni/N) x 100

In the equation, Ni represents the number of species of a specific category (family/habitat) recorded, and N is the total number of species recorded. This was done by using descriptive statistics to summarise family richness and the distribution of life forms and assessing spatial patterns by comparing the presence of the species on the major landscape units in the Cholistan Desert.

Statistical analysis of diversity

Plant diversity was studied as part of a list of fifty-eight plant species found in the Cholistan Rangelands. Species richness (S) was the number of species that were recorded. Family richness was the number of plant families that were found. This was based on the work of Magurran (2004) and Colwell (2009). The share of each family was found by dividing the number of species in that family by the total number of species. The formula used was p i equals n i divided by N. N i is the number of species in family i, and N is the total number of species recorded (Magurran, 2004; Colwell, 2009). Species richness is the number of species in a group or a sample. The proportional abundance (p i) is the starting point for diversity measures, like the Shannon index and the Simpson index (Magurran, 2004; Krebs, 1999).

Family-level diversity was evaluated using the Shannon-Wiener diversity index (H′), Simpson dominance index (D), Simpson diversity index (1−D), and Pielou's evenness index (J′). Shannon diversity was calculated as:

$$H' = -i=1\sum Sfpiln(pi)$$

where pi is the proportion of species represented by family i and Sf is the total number of families. Simpson dominance was calculated as:

$$D = i=1\sum Sfpi2$$

and Simpson diversity was expressed as 1−D. Pielou's evenness was calculated as:

$$J' = \ln(Sf)H'$$

where Sf is the number of families.

The same approach was used to describe the distribution of species among important habitat categories. Habitat-level species richness was calculated from the number of species recorded in each habitat category, and Shannon, Simpson and Pielou indices were calculated from the representation of species among habitats (Table 3).

Results

Floristic composition and distribution of plant species

A detailed floristic survey of the Cholistan Rangelands demonstrated fifty-eight representative species of vascular flora distributed among 19 families of plants in various desert habitats like active sand dune, stabilized sand dune, interdunal plain, saline depression (Dahars), ephemeral drainage channels (Kas), Toba margins, shrublands, agricultural ecotones and alluvial plains (Table 1). The family with the highest number of species was Asteraceae with nine species

(15.5%), followed by Aizoaceae, Capparaceae and Chenopodiaceae with six species each (10.3%). Five species each (8.6%) were found in Amaranthaceae and Asclepiadaceae (now treated within Apocynaceae). Poaceae and Boraginaceae each contained four species (6.9%), while Brassicaceae contained three species (5.2%). One species each (1.7%) was recorded in Convolvulaceae, Fabaceae, Polygonaceae, Rhamnaceae, Salvadoraceae, Mimosaceae, Caesalpiniaceae, Caryophyllaceae, Asphodelaceae and Zygophyllaceae (Table 1).

The dominance of Asteraceae, Aizoaceae, Amaranthaceae, Chenopodiaceae, Capparaceae and Poaceae indicates that these families are ecologically adapted to withstand the very dry conditions, high temperatures and sandy substrates of the Cholistan Desert and saline conditions (Figure 7). The representative flora comprised the following important species of perennial desert plants: *Cenchrus ciliaris, Lasiurus scindicus, Haloxylon salicornicum, Capparis decidua, Calligonum polygonoides, Prosopis cineraria, Leptadenia pyrotechnica, Salvadora oleoides, Ziziphus nummularia* and *Panicum turgidum* (Table 1). They contributed to the structural vegetation of stabilized dunes, shrublands, sandy plains, and alluvial habitats. Annual herbs have qualities related to seasonal moisture availability, disturbed habitats, and ephemeral desert habitats. These plants include *Trianthema portulacastrum, Gisekia pharnaceoides, Amaranthus viridis, Digera muricata, Launaea capitate* and *Gnaphalium luteo-album.*

Spatial distribution across habitats

There was significant variation in the distribution of the plant species from one landscape unit to another in the Cholistan Rangelands (Table 1). Sand dunes (18 species, 31.0%), sandy plains (10 species, 17.2%), and shrubland/interdunal habitats (8 species, 13.8%) had the greatest numbers of representative species. Six species (10.3%) grew on agricultural ecotones, five species (8.6%) on saline dahars, and four (6.9%) on drainage channels and toba margins. Three species (5.2%) were found in special and disturbed habitats. (Table 1). The xerophytic species of *Lasiurus scindicus, Calligonum polygonoides* and *Leptadenia pyrotechnica* were associated with active dune systems and were associated with unstable sand formation. The stabilized dunes were covered by perennial grasses and shrubs, including *Cenchrus ciliaris, Cymbopogon jwarancusa* and *Aerva javanica* (Table 1). Woody desert species (*Haloxylon salicornicum, Prosopis cineraria* and *Alhagi maurorum*) grew on sandy plains and interdunal landscapes. The halophytic species like *Haloxylon stocksii, Salsola* imbricata and *Suaeda fruticosa* predominated in saline depressions (Dahars). Species such as *Eclipta alba, Oxystelma esculentum* and *Salvadora oleoides* were relatively

moisture-dependent species associated with moister microhabitats found on Toba margins and ephemeral drainage channels (Table 1). Annual herbs were found in disturbed habitats and in areas of transition between agriculture and natural areas, suggesting they require short periods of time to be moist after the seasonal rains (Figure 3).

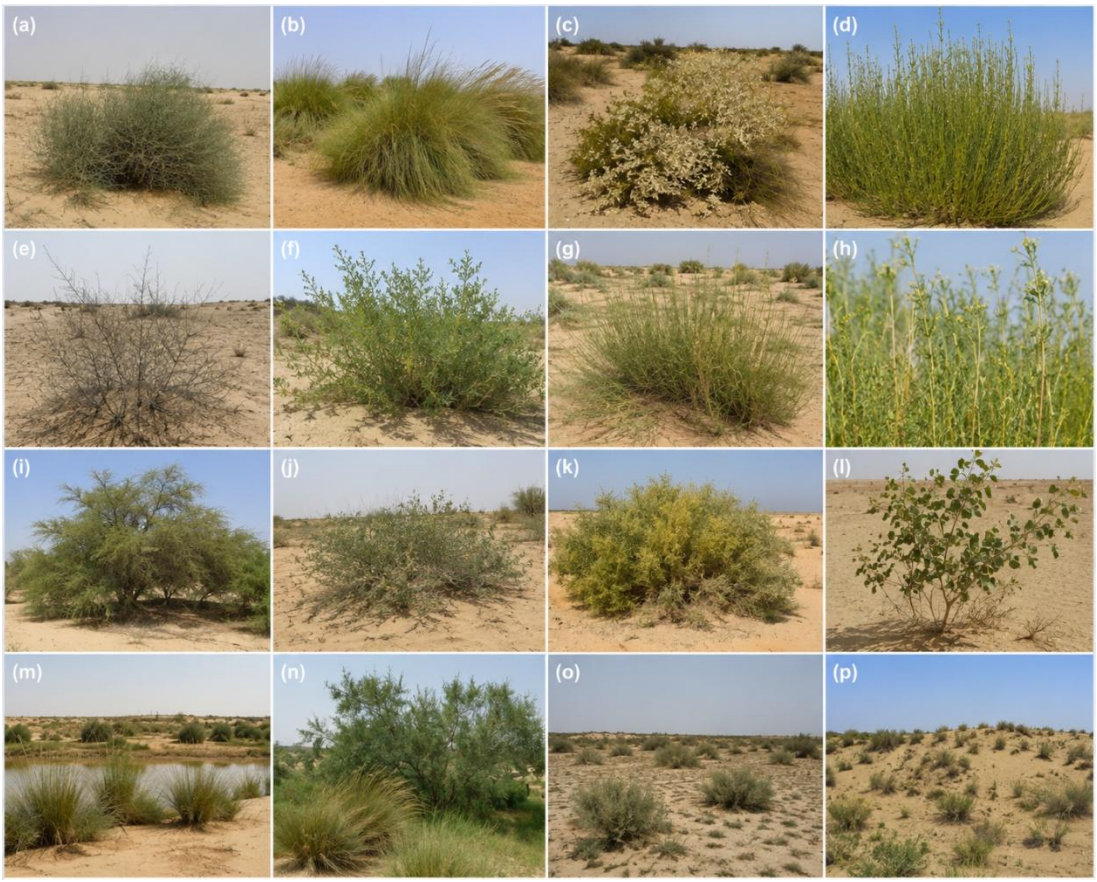

Figure 3. Floras including: (a) *Haloxylon salicornicum; (b) Lasiurus scindicus; (c) Aerva javanica; (d) Leptadenia pyrotechnica; (e) Calligonum polygonoides; (f) Haloxylon stocksii; (g) Cenchrus ciliaris; (h) Farsetia hamiltonii; (i) Prosopis cineraria; (j) Capparis decidua; (k) Suaeda fruticosa; (l) Salvadora oleoides; (m) Panicum turgidum; (n) Prosopis cineraria* with related perennial grasses; *(o)* Mixed vegetation is dominated by *Haloxylon salicornicum* and *Lasiurus scindicus*; *(p)* Active sand dune vegetation are dominated by *Lasiurus scindicus* and *Calligonum polygonoides*

Life form composition

The species demonstrated difference in their life-forms represent different life strategies to cope with the environment. Therophytes were abundant life-form group and consisted of annual herbs that are able to complete their life cycle during moisture events. They were associated with sandy plains and ephemeral habitats. Another important group of life forms were the chamaephytes, drought-tolerant shrubs and subshrubs that thrive in intense solar radiation, high temperatures and

low water. Among the hemi-cryptophytes, the dominant species were perennial grasses with significant roles in soil stabilization and desert rangeland productivity such as *Cenchrus ciliaris, Lasiurus scindicus and Panicum turgidum*. Phanerophytes (large shrubs, trees) were few in number, but important in providing habitat structure, wind erosion control and associated desert fauna. Herbaceous plants were the most abundant growth form followed by grasses, shrubs, trees, subshrubs and climbers (Table 1).

Table 1. Botanical Inventory, Spatial Mapping and Landscape Distribution across the Cholistan Rangelands

Sr. No.	Floral Species	Family	Type	Life Cycle	Sampling Location	Coordinates	Landscape	Height (cm)
1	*Cenchrus ciliaris* L. (Dhaman)	Poaceae	Grass	Perennial	Derawar Fort	28.7681° N, 71.3342° E	Stabilized sand ridges	69
2	*Lasiurus scindicus* Henrard (Sewan)	Poaceae	Grass	Perennial	Yazman Desert	29.0210° N, 71.8520° E	Active sand dunes	99
3	*Haloxylon salicornicum* (Moq.) Bunge (Lana)	Chenopodiaceae	Shrub	Perennial	Dingarh	28.9426° N, 71.8371° E	Sandy plains matrix	87
4	*Capparis decidua* (Forssk.) Edgew. (Karir)	Capparaceae	Tree	Perennial	Channan Pir	28.9245° N, 71.8973° E	Interdunal drainage basin	283
5	*Calligonum polygonoides* L. (Phog)	Polygonaceae	Shrub	Perennial	Khairpur Sand Core	29.5823° N, 71.9127° E	Mobile dune crests	147
6	*Tribulus terrestris* L. (Bhakhra)	Zygophyllaceae	Herb	Annual	Derawar Fort	28.7685° N, 71.3368° E	Sandy flats terrain	17
7	*Alhagi maurorum* Medik. (Jawahan)	Fabaceae	Shrub	Perennial	Tibba Lal Suhanra	28.6124° N, 71.8569° E	Sandy-clay buffer plains	64
8	*Ziziphus nummularia* (Burm.f.) Wight (Ber)	Rhamnaceae	Shrub	Perennial	Yazman West	29.1038° N, 71.6984° E	Consolidated low shrubland	186
9	*Aerva javanica* (Burm.f.) Juss. (Bui)	Amaranthaceae	Subshrub	Perennial	Derawar Desert	28.7531° N, 71.3572° E	Undulating dune slopes	93
10	*Panicum turgidum* Forssk. (Murrot)	Poaceae	Grass	Perennial	Dingarh	28.9416° N, 71.8423° E	Dry drainage tracks	98
11	*Cleome viscosa* L. (Kastoori)	Capparaceae	Herb	Annual	Yazman East	29.1472° N, 71.7781° E	Disturbed sandy soils	53
12	*Salvadora oleoides* Decne. (Pilu)	Salvadoraceae	Tree	Perennial	Mojgarh	29.0132° N, 72.1401° E	Catchment pond margins	527
13	*Prosopis cineraria* (L.) Druce (Jand)	Mimosaceae	Tree	Perennial	Derawar Region	28.7814° N, 71.3478° E	Alluvial plain matrix	793
14	*Cymbopogon jwarancusa* Schult. (Khavi)	Poaceae	Grass	Perennial	Channan Pir	28.9245° N, 71.8973° E	Stabilized dune flanks	97
15	*Leptadenia pyrotechnica* Decne. (Khip)	Asclepiadaceae	Shrub	Perennial	Fort Abbas	29.1923° N, 72.8534° E	Dynamic dune hummocks	143

Sr. No.	Floral Species	Family	Type	Life Cycle	Sampling Location	Coordinates	Landscape	Height (cm)
16	*Gisekia pharnaceoides* Linn. (Baluka Sag)	Aizoaceae	Herb	Annual	Nawankot	28.3412° N, 71.4239° E	Ephemeral sand flats	27
17	*Limeum indicum* Stocks	Aizoaceae	Herb	Annual	Bijnot	28.0815° N, 71.7542° E	Gravel desert margins	24
18	*Sesuvium sesuvioides* Verdc. (Barri Ulwaiti)	Aizoaceae	Herb	Annual	Islamgarh Fort	27.8551° N, 70.8079° E	Saline clay pans	28
19	*Trianthema portulacastrum* Linn. (Wisah)	Aizoaceae	Herb	Annual	Kudwala	29.1894° N, 71.8845° E	Agricultural ecotone buffers	43
20	*Trianthema triquetra* Willd. (Choti Ulwaiti)	Aizoaceae	Herb	Annual	Phoolra Fort	29.0215° N, 72.4861° E	Baked alkaline clearings	29
21	*Zaleya pentandra* Linn. (Itsit, Wisah)	Aizoaceae	Herb	Perennial	Yazman Border	29.1311° N, 71.7214° E	Compacted pastoral terrain	42
22	*Aerva javanica* var. *bovei* Webb (Bui Bui)	Amaranthaceae	Subshrub	Perennial	Mojgarh Core	29.0115° N, 72.1524° E	Wind-scoured dune slopes	81
23	*Amaranthus graecizans* Gusev	Amaranthaceae	Herb	Annual	Marot Ecotone	29.1712° N, 72.4115° E	Abandoned pastoral spaces	52
24	*Amaranthus viridis* Linn.	Amaranthaceae	Herb	Annual	Head Rajkan	29.2845° N, 71.8123° E	Canal drainage banks	74
25	*Digera muricata*	Amaranthaceae	Herb	Annual	Dingarh North	28.9514° N, 71.8445° E	Transient water paths	61
26	*Calotropis procera* (Ak)	Asclepiadaceae	Shrub	Perennial	Derawar Perimeter	28.7756° N, 71.3214° E	Degraded infrastructure borders	257
27	*Caralluma edulis* (Edgew.) Hook.f. (Seetu)	Asclepiadaceae	Herb	Perennial	Rahim Yar Khan Desert	28.6451° N, 70.6845° E	Protected shrub shade	29
28	*Oxystelma esculentum* R. Brown (Dudhani)	Asclepiadaceae	Climber	Perennial	Jamgarh Fort	28.5614° N, 71.5912° E	Wet splash zones	156
29	*Pentatropis spiralis* (Forssk.) Decne.	Asclepiadaceae	Climber	Perennial	Mojgarh Shrubland	29.0172° N, 72.1445° E	Deep sandy woodlands	118
30	*Asphodelus tenuifolius* Cav. (Piazi)	Asphodelaceae	Herb	Annual	Yazman Outskirts	29.1512° N, 71.7912° E	Cultivated edge zones	37
31	*Echinops echinatus* Roxb. (Unt katara)	Asteraceae	Herb	Perennial	Nawankot Basin	28.3245° N, 71.4478° E	Hardened clay tracks	53
32	*Eclipta alba* Hassk. (Bhangra)	Asteraceae	Herb	Perennial	Toba Ghansoor	28.9812° N, 71.4112° E	Saturated basin floors	41
33	*Gnaphalium luteo-album* Linn.	Asteraceae	Herb	Annual	Channan Pir Oasis	28.9112° N, 71.9214° E	Topographic hollow basins	29
34	*Launaea capitata* (Spreng.) Dandy	Asteraceae	Herb	Annual	Dingarh Outpost	28.9412° N, 71.8545° E	Interdunal loamy sands	34
35	*Launaea nudicaulis* Less. (Bhattal)	Asteraceae	Herb	Perennial	Mirana Camp	28.6945° N, 71.2112° E	Nomadic transit corridors	42
36	*Launaea resedifolia* O. Kuntz.	Asteraceae	Herb	Annual	Khairpur Sand Core	29.5912° N, 71.8912° E	Dynamic sand sheets	31

Sr. No.	Floral Species	Family	Type	Life Cycle	Sampling Location	Coordinates	Landscape	Height (cm)
37	Asteraceae sp. (Barim Dandi)	Asteraceae	Herb	Perennial	Fort Abbas West	29.1812° N, 72.8214° E	Gravelly saline plains	NA
38	*Pulicaria crispa* Benth. & Hook.f. (Bui)	Asteraceae	Subshrub	Perennial	Alkaline Dahars	28.4112° N, 71.6545° E	Hyper-alkaline flat zones	54
39	*Xanthium strumarium* Linn.	Asteraceae	Shrub	Annual	Derawar Village	28.7612° N, 71.3412° E	Domestic clearing borders	97
40	*Arnebia hispidissima* (Lehm.)	Boraginaceae	Herb	Annual	Walhar Range	28.2112° N, 71.1214° E	Skeletal dune bases	36
41	*Heliotropium crispum* Desf. (Kali Bui)	Boraginaceae	Subshrub	Perennial	Yazman Dunes	29.0112° N, 71.8512° E	Severe crest lines	43
42	*Heliotropium europaeum* var. *lasiocarpum*	Boraginaceae	Subshrub	Annual	Kudwala Track	29.1712° N, 71.8945° E	Altered track borders	38
43	*Heliotropium strigosum* subsp. *strigosum* (Gorakh Pan)	Boraginaceae	Herb	Perennial	Dingarh Range	28.9412° N, 71.8314° E	Well-drained sand flats	32
44	*Farsetia hamiltonii* Royle (Fareed Buti)	Brassicaceae	Shrub	Perennial	Fort Abbas Core	29.1614° N, 72.8415° E	Loose slip-face dunes	52
45	*Farsetia jacquemontii* Hook.f. (Fareed Buti)	Brassicaceae	Shrub	Annual	Channan Pir East	28.9312° N, 71.8812° E	Wind-blown deposition sheets	41
46	*Malcolmia africana* var. *africana*	Brassicaceae	Herb	Annual	Lal Suhanra Margin	28.6214° N, 71.8412° E	Shaded microclimatic hollows	28
47	*Cassia italica* subsp. *italica* (Deasi Sana)	Caesalpiniaceae	Shrub	Annual	Mojgarh Bed	29.0112° N, 72.1414° E	Dry outwash beds	96
48	*Capparis spinosa* Linn. (Kubber)	Capparaceae	Shrub	Perennial	Derawar Ruins	28.7656° N, 71.3312° E	Vertical masonry crevices	104
49	*Cleome brachycarpa* Vahl. (Noli)	Capparaceae	Herb	Perennial	Bijnot Slopes	28.0912° N, 71.7412° E	Stony desert hillsides	48
50	*Cleome scaposa* DC. (Noli)	Capparaceae	Herb	Annual	Nawankot Core	28.3512° N, 71.4112° E	Compacted gravel pavements	39
51	*Dipterygium glaucum* Decne. (Fehl)	Capparaceae	Subshrub	Perennial	Greater Cholistan Dunes	28.4051° N, 71.4347° E	Unstable dune system	72
52	*Spergularia marina* (Linn.) Griseb.	Caryophyllaceae	Herb	Annual	Toba Saline	28.4512° N, 71.3112° E	Evaporation pool halos	26
53	*Chenopodium album* Linn. (Bathu)	Chenopodiaceae	Herb	Annual	Kudwala Inlets	29.1912° N, 71.8712° E	Alluvial silt deposits	72
54	*Chenopodium murale* Linn.	Chenopodiaceae	Herb	Annual	Yazman Center	29.1412° N, 71.7412° E	Urban-desert interface clearings	51
55	*Haloxylon stocksii* (Boiss.) Benth. (Khar, Sajji)	Chenopodiaceae	Shrub	Perennial	Alkaline Dahars	28.3845° N, 71.6112° E	Hyper-saline clay flats	126

Sr. No.	Floral Species	Family	Type	Life Cycle	Sampling Location	Coordinates	Landscape	Height (cm)
56	*Salsola imbricata* var. *imbricata* (Lani)	Chenopodiaceae	Shrub	Perennial	Dingarh Saline Basin	28.9412° N, 71.8612° E	Enclosed basin bottoms	97
57	*Suaeda fruticosa* Forssk. ex J.F. Gmelin (Kali Lani)	Chenopodiaceae	Shrub	Perennial	Fort Abbas Marshy Dahars	29.1512° N, 72.8112° E	Waterlogged marshy plains	103
58	*Convolvulus prostratus* Forssk. (Hiran Buti)	Convolvulaceae	Herb	Perennial	Channan Pir Cor	28.9212° N, 71.8912° E	Semi-loamy trail edges	31

Ecological significance

Spatial distribution patterns of representative plant species showed relationships between the vegetation composition and the habitat characteristics all over the Cholistan Desert. Species occurrence was mostly affected by landscape disturbance, dune stability, moisture availability, soil salinity, and substrate type (Table 1). In dune systems, exposed systems were dominated by xerophytic shrubs and perennial grasses, and saline Dahars and moisture-accumulating depressions were dominated by halophytic vegetation. Species requiring moisture in their environment were found around Tobas, drainage channels, and agricultural ecotones, indicating the significance of local moisture availability for plant diversity in this hyper-arid ecosystem. The recorded flora included some annuals and perennials. Annual species were typically growing with therophytic herbs in disturbed soils, interdunal plains, and seasonally moist soils (Table 1).

Geographic distribution of records

The 58 vascular plant records were distributed between 27.8551–29.5912° N latitude and 70.6845–72.8534° E longitude. Areas of concentration of the records were found at Derawar, Dingarh, Channan Pir, Yazman, Mojgarh and Fort Abbas, while records from some desert areas and Khairpur Sand Core were near the extreme ends of the coordinate range surveyed. A provisional operational division was used in the present study with 35 records (60.3%) classified as part of Greater Cholistan and 23 records (39.7%) as part of Lesser Cholistan. Each point has a corresponding serial number in the floristic inventory. The geographical division accepted here is based on the bed of the Hakra River, which is not a regular boundary, so the geographical classification based on this coordinate should be considered provisional. In Figure 4, bold numbers correspond to the serial numbers of plant species in the floristic inventory, while leader lines connect the numbered labels to their exact geographic coordinates.

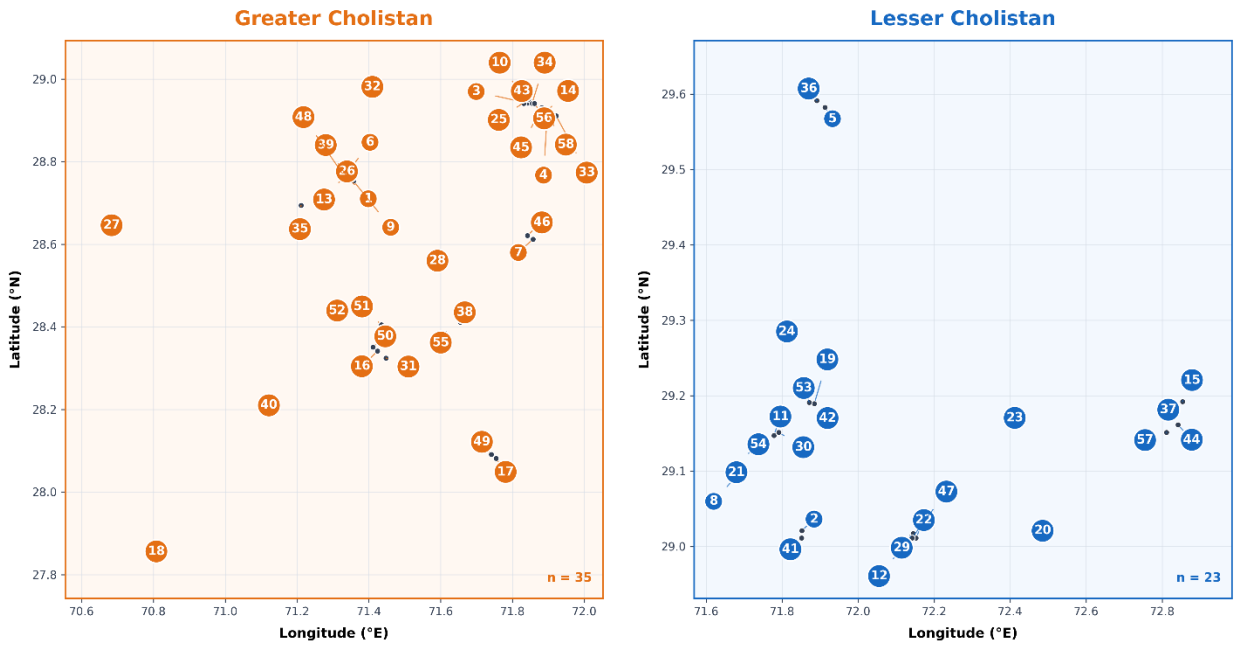

Figure 4. Coordinates distribution of plant species in the Lesser and Greater Cholistan. The figure shows the geographic distribution of 58 plant species across the Cholistan region based on latitude and longitude. Most of the Greater Cholistan records occur south of the 29° N division, whereas Lesser Cholistan records are concentrated mainly to the north

Table 2. Statistics and height-class distribution of measured plant species

Structural attribute	Value
Total vascular plant species	58; n = 57
Minimum recorded height	17 cm
Maximum recorded height	793 cm
Height range	776 cm
Mean recorded height	93.5 cm
Median recorded height	53 cm
Standard deviation	123.9 cm
Coefficient of variation	132.5%

Structural attribute	Value
Species ≤50 cm	24
Species 51–100 cm	21
Species 101–200 cm	8
Species >200 cm	4

Most recorded plant species occurred in the shorter height classes. Of the 57 species with recorded heights, 24 species (42.1%) were ≤50 cm tall, while 21 species (36.8%) were 51–100 cm tall. Eight species (14.0%) occurred in the 101–200 cm class, and four species (7.0%) exceeded 200 cm. Thus, 78.9% of the measured flora was ≤100 cm tall, indicating that low-growing plants dominated the surveyed vegetation (Figure 5).

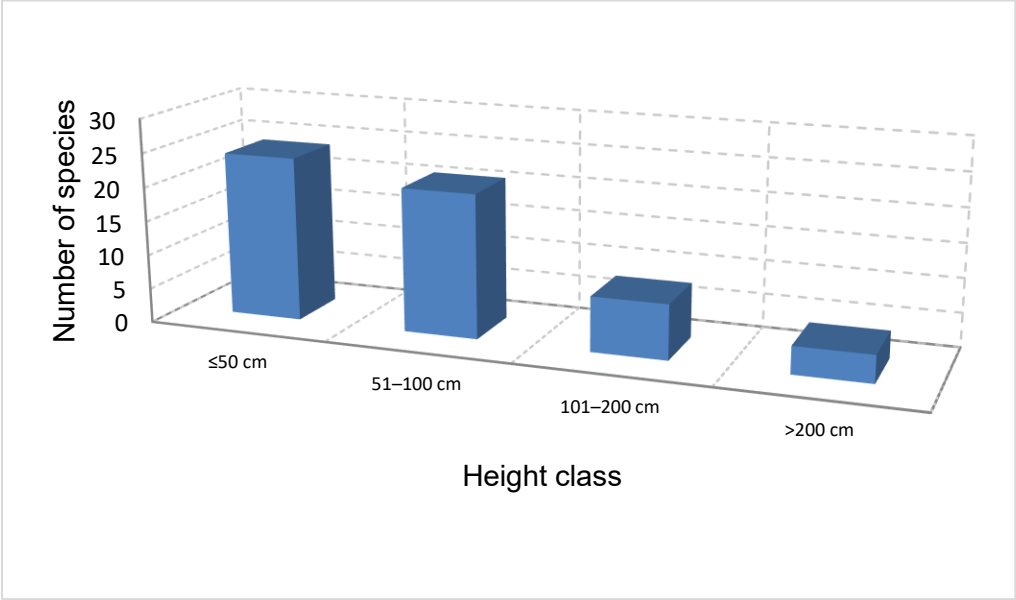

Figure 5. Distribution of 57 measured plant species among height classes

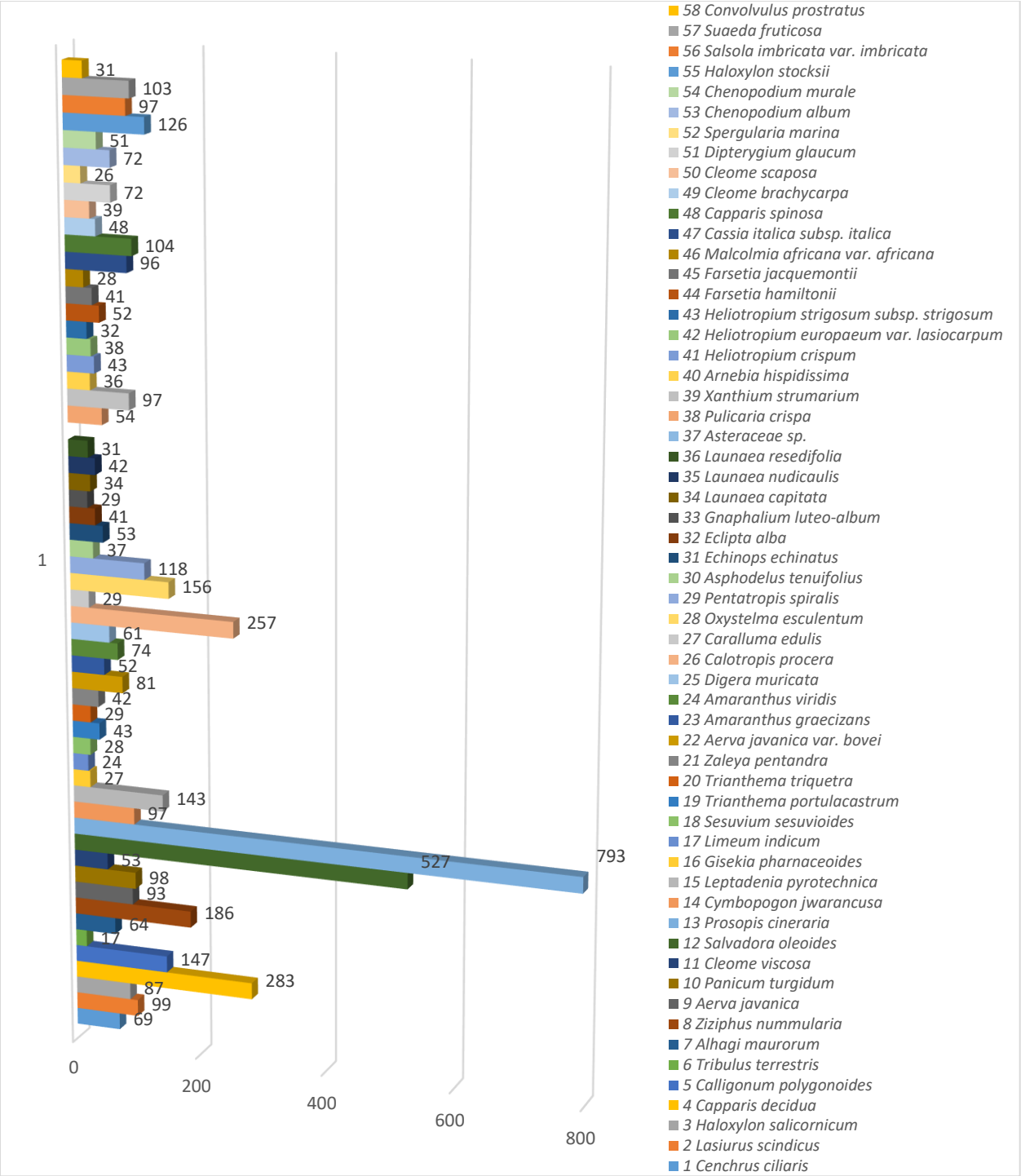

Figure 6. Recorded height of individual plant species

Height-class distribution and family-wise species richness

Among the 57 species with recorded heights, 24 species (42.1%) were in the height class of ≤50 cm, 21 species (36.8%) were in the height class of 51–100 cm, eight species (14.0%) had a height of 101–200 cm, and four species (7.0%) exceeded 200 cm in height. The growth form of low

herbs/grasses and subshrubs is an adaptation to the hyper-arid environment of the Cholistan Rangelands, while the low number of tall shrubs and trees reflects the scarcity of favourable microsites that can support larger perennial vegetation. This observed height structure shows the value of structural stratification in maintaining habitat heterogeneity and ecological resilience in desert landscapes. The height-class distribution shows that most measured species occupied the lower height classes, with few woody perennial species in the upper structural classes of the vegetation. The 58 plant species recorded in the Cholistan Desert belonged to 19 families (Table 1). Asteraceae had the highest representation (9 species; 15.5%), followed by Aizoaceae, Capparaceae and Chenopodiaceae (6 species each; 10.3%). Amaranthaceae and Asclepiadaceae each had 5 species (8.6%), Poaceae and Boraginaceae each had 4 species (6.9%), and Brassicaceae had 3 species (5.2%). Convolvulaceae, Fabaceae, Polygonaceae, Rhamnaceae, Salvadoraceae, Mimosaceae, Caesalpiniaceae, Caryophyllaceae, Asphodelaceae and Zygophyllaceae were each represented by one species (1.7%). The prominence of Asteraceae, Aizoaceae, Amaranthaceae, Chenopodiaceae and Poaceae is characteristic of desert flora adapted to the extreme arid and saline environment of the Cholistan Desert (Figure 7).

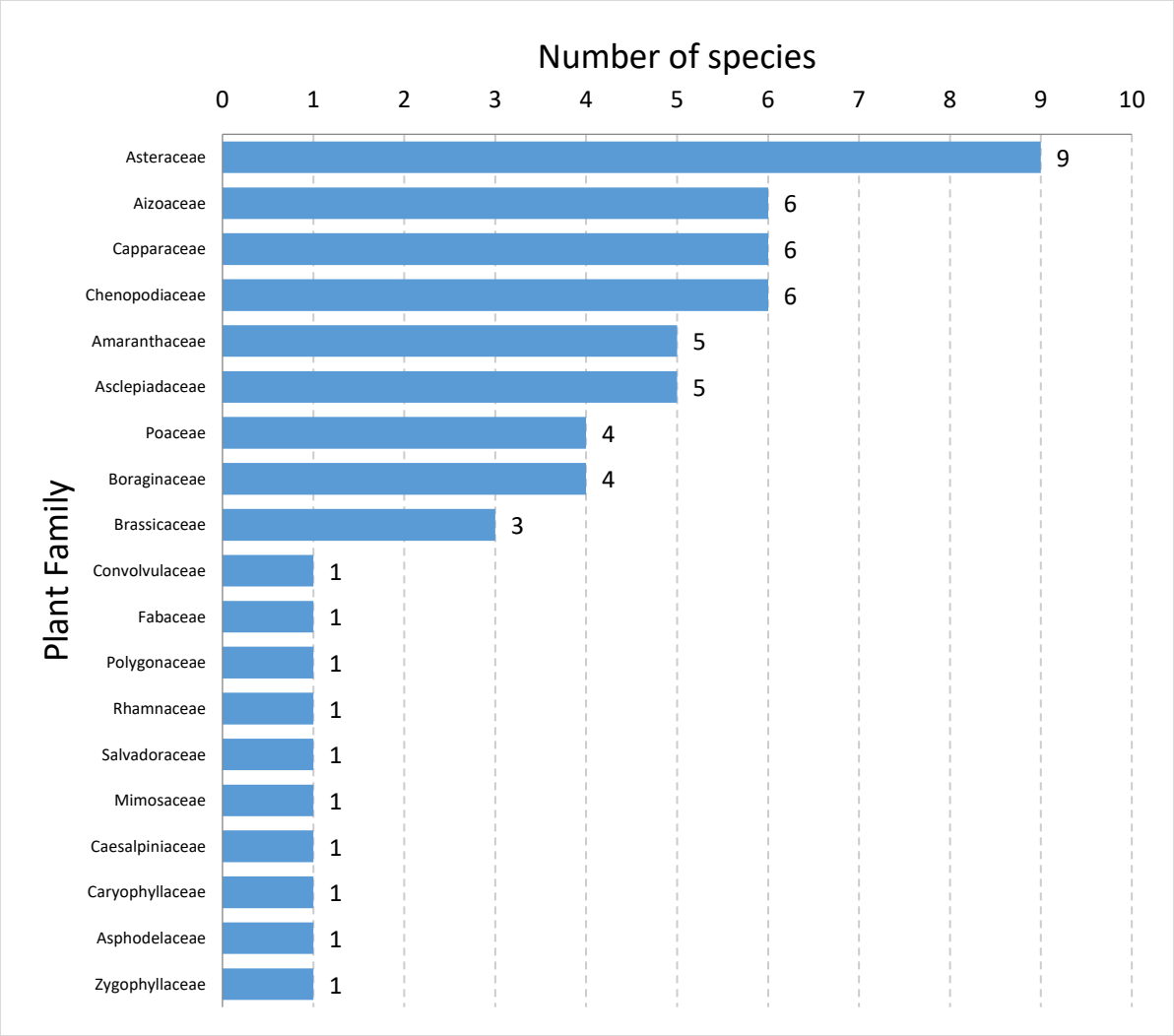

Figure 7. Family-wise distribution of plant species recorded from the Cholistan Rangelands

Habitat-wise distribution of representative species

The representative flora covered a diverse range of desert habitats (Table 1). Sand dune habitats had the most representative species, with 18 species (31.0%), followed by sandy plains with 10 species (17.2%) and interdunal or shrubland habitats with 8 species (13.8%). Cultivated margins and agricultural ecotones supported 6 species (10.3%), while saline dahars supported 5 species (8.6%). Four species (6.9%) were found in drainage channels/dry watercourses and 4 species (6.9%) in Toba margins (Figure 8). Other special habitats, disturbed settlements, and archaeological sites were the habitats for the remaining 3 species (5.2%). The results suggest that the representative desert vegetation is found primarily under the stable and mobile sand dune systems (Figure 8).

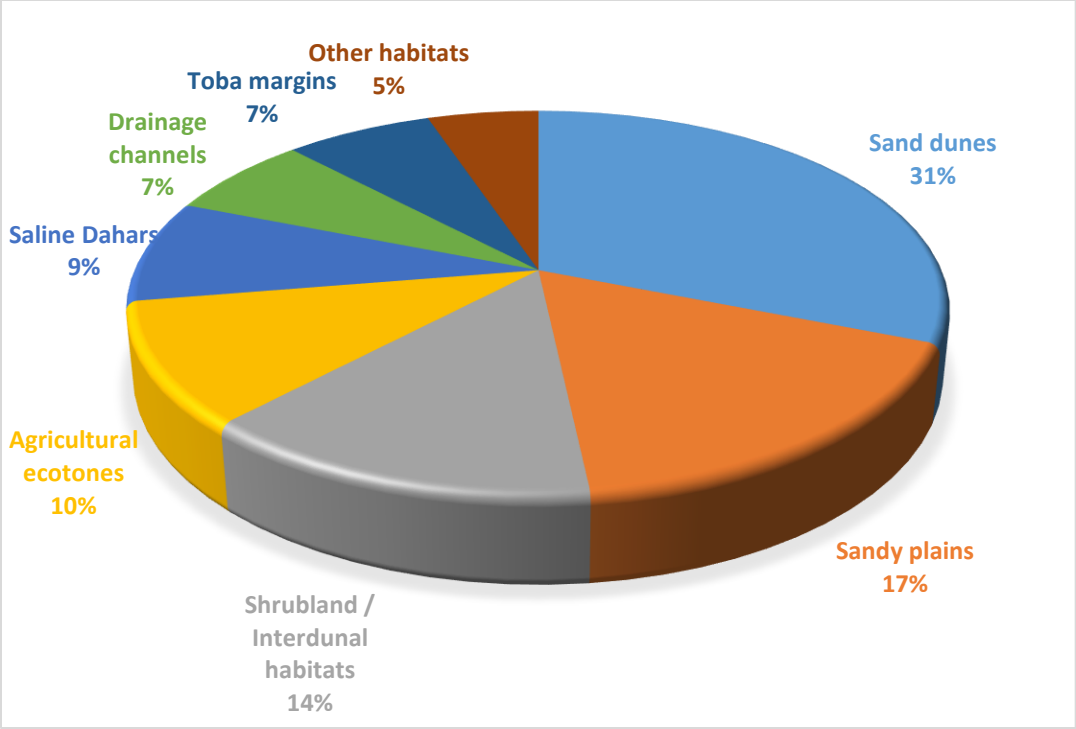

Figure 8. Habitat-wise distribution of representative plant species

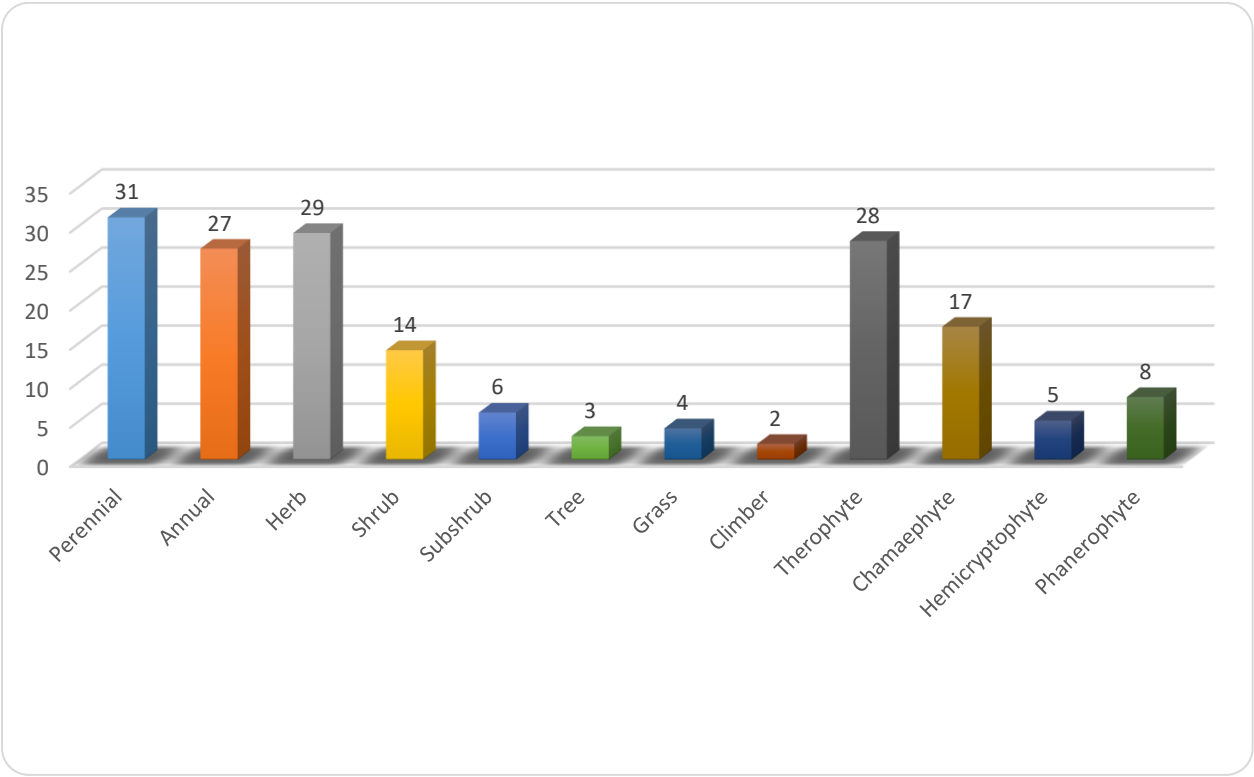

Figure 9. Number of different kinds of plant species observed during the study

Plant diversity statistics

A total of 58 plant species belonging to 19 families were recorded. Asteraceae was the most species-rich family, with 9 species (15.5%). Aizoaceae, Capparaceae and Chenopodiaceae followed with 6 species each (10.3%). Amaranthaceae and Asclepiadaceae each had 5 species (8.6%), Poaceae and Boraginaceae each had 4 species (6.9%), and Brassicaceae had 3 species (5.2%). The remaining 10 families each had one species (1.7%). Thus, all 58 species and all 19 families are accounted for consistently in the floristic inventory and family summary table.

The Shannon diversity index was 2.638, Simpson dominance was 0.086, Simpson diversity was 0.914, and Pielou's evenness was 0.896. These values indicate that the 58 species were broadly distributed among families rather than concentrated in a few families, although Asteraceae remained the most species-rich family. Species representation also differed among habitats. Sand dunes contained 18 species, sandy plains 10, shrubland/interdunal habitats 8, agricultural ecotones 6, saline habitats 5, drainage channels 4, Toba margins 4, and other habitats 3, accounting for all 58 species. At the habitat level, Shannon diversity was 1.907, Simpson dominance was 0.175, Simpson diversity was 0.825, and Pielou's evenness was 0.917. These values indicate a relatively even distribution among habitats, although sand dunes supported the greatest number of species (Table 3).

Table 3. Diversity-index comparison between taxonomic and habitat components

Diversity measure	Family level (19 families)	Habitat level (8 habitats)	Relative Pattern
Species observations represented	58	58	Same floristic inventory
Number of categories	19	8	Greater at family level
Shannon diversity, H′	2.638	1.907	Higher at family level
Simpson dominance, D	0.086	0.175	Lower family dominance
Simpson diversity, 1−D	0.914	0.825	Higher family diversity
Pielou evenness, J′	0.896	0.917	High at both levels
Maximum possible H′	ln(19) = 2.944	ln(8) = 2.079	—
Relative Shannon diversity (H′/H′max)	89.6%	91.7%	High evenness
Dominant category	Asteraceae	Sand dunes	—
Dominant category contribution	15.5%	31.0%	—

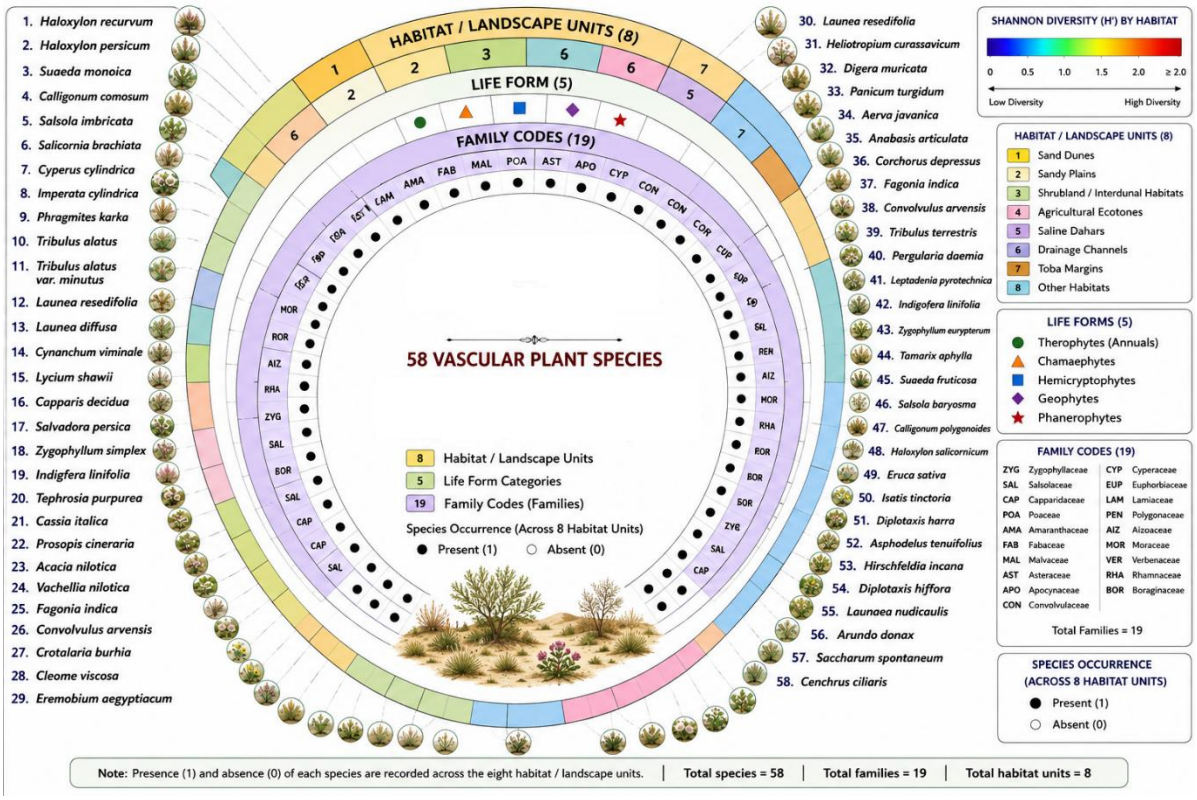

Figure 10. Diversity richness of important species of plants in the rangelands

The circular summary illustrates the distribution of 58 plant species across the Cholistan Rangelands (Figure 10). The inventory represents eight habitat categories, five growth forms and 19 plant families, demonstrating considerable ecological heterogeneity across the study area. Sand dunes and sandy plains supported the greatest numbers of recorded species. The flora was dominated by drought adapted families, particularly Asteraceae, Aizoaceae, Capparaceae, Chenopodiaceae, Amaranthaceae and Poaceae. Many recorded plants were annual or low-growing species, reflecting adaptation to aridity and high temperatures. The occurrence of xerophytes, halophytes and moisture associated species further indicates that habitat conditions influence floristic composition. Figure 10 therefore summarizes taxonomic composition, habitat distribution and ecological characteristics of the recorded flora.

Discussion

In present study 58 species representing 19 families of vascular plants were recorded from major habitats of Cholistan Rangelands. This is significant floristic diversity at the sampled sites but less than that reported by Wariss et al. (2013) in their wider floristic survey of Cholistan Desert across

seasons during 2009-2011 which reported 154 species, 106 genera and 38 families. This may be due to the extent of the survey, its sampling design, habitat cover and seasonal sampling and not just a decline in regional flora. In the present dataset, Asteraceae was the most species-rich family. This difference implies that the family-level dominance may differ significantly depending on the habitat and the spatial size of a survey. The present results also support well with the previous ecological evaluation of Arshad and Akbar (2002) which identified 16 plant communities along the various landforms of Cholistan. In their study they found that *Calligonum polygonoides*, *Haloxylon salicornicum*, *Lasiurus scindicus*, *Prosopis cineraria*, *Capparis decidua*, *Suaeda fruticosa* are of special importance in the vegetation of Cholistan.

The Cholistan Rangelands contain diverse habitats, with some species associated with sand dunes and others with saline or moisture-influenced sites. Dune vegetation contributes to sand stabilization, whereas halophytic vegetation tolerates elevated soil salinity (Akbar et al., 1996; Arshad & Akbar, 2002). The recorded plants exhibit adaptations to severe aridity, including deep root systems, salinity tolerance and the capacity to withstand prolonged water limitation (Naz et al., 2010, 2013). Moisture-associated species contribute to soil stabilization and provide habitat resources for desert fauna (Noy-Meir, 1973; Austin et al., 2004; Haider et al., 2022). Collectively, these habitats support substantial floristic diversity and their protection is important for maintaining biodiversity, ecosystem functioning and ecological stability (Reynolds et al., 2007; Maestre et al., 2012a, 2012b, 2016; Berdugo et al., 2020).

In the present study, several of these species were also found in dune, sandy-plain, shrubland and saline habitats. Arshad & Akbar (2002) also reported that therophytes were more prevalent during the rainy season, while perennial trees/shrubs/grasses/herbs were more prevalent in more stable plant communities. This is similar to the dominance of therophytes and drought-tolerant plants found in the present survey. The habitat differentiation observed in the present study is also corroborated by the previous studies on the vegetation of Cholistan. A previous study of four rangeland habitats demonstrated floristic differences and differences in plant diversity, and suggested that vegetation patterns were primarily controlled by topographic and edaphic factors. In that study grasses were determined as significant vegetation components in the habitats studied. The present study takes this habitat approach a step further by providing more detailed information on the distribution of species in a broader spectrum of landscape categories such as sand dunes, sandy plains, shrubland/interdunal habitats, agricultural ecotones, saline Dahars, drainage

channels and Toba margins. Of these habitats, sand dunes had the greatest number of species (eighteen), and in the present study, sandy plains had a higher number of species (ten). This is consistent with previous descriptions of Cholistan. According to Wariss et al. (2013), dune vegetation consists of grasses, *Cenchrus ciliaris*, *Panicum turgidum* and *Lasiurus scindicus* and perennial shrubs *Calligonum polygonoides* and *Leptadenia pyrotechnica*. These characteristic xerophytic grasses and shrubs show that dune environments are not just bare and unproductive land forms, but also harbor plant communities that are suited to the dynamic sand surfaces and water stress. The present study is in agreement with previous studies, particularly with regard to the vegetation of saline Dahars. A variety of species were correlated with saline habitats in the present study, including *Suaeda fruticosa*. Five habitats of Cholistan were examined by Naz et al. (2010) and they showed that the plant community structure and species distribution varied significantly across the salinity gradient. Among the important components of highly saline sites, they specifically mentioned *Suaeda fruticosa* and *Haloxylon recurvum*. Therefore, the present study showed that the concentration of halophytic vegetation with saline dahars is in line with the salinity vegetation relationship for the dahars of Cholistan, which is established through experiments.

This interpretation is corroborated by Naz et al. (2013), who studied the soil–plant interactions along salinity gradient of Cholistan. They observed significant differences in salinity tolerance and distribution between species; *Suaeda fruticosa* being associated with the dominant plants at the highest salinity, while *Lasiurus scindicus* was mainly associated with the lower to moderate salinity. They also concluded that salinity alone is not the only factor determining vegetation structure; species-specific tolerance limits and life-history characteristics are also important. Based on the present results, the contrasting floristic composition of dunes, sandy plains and saline dahars may be attributed to the combined effects of the nature of the substrate, salinity, water availability and species tolerances. The Toba margins and drainage-associated habitats are also of importance in the present study as their importance is supported by more recent quantitative research studies. An ecological assessment was conducted around 100 Cholistan Tobas in 2022 and four plant communities were identified with 49 species belonging to 25 families. Importantly, that study revealed that soil moisture, organic matter, available phosphorus, and grazing pressure were important environmental factors affecting the structure of the vegetation and plant-community formation. Local differences in moisture availability and soil characteristics, as revealed from the

present observation of Toba margins and drainage channels yielding distinctive plant assemblages, are thus consistent with the evidence of localized moisture availability and soil conditions in the vegetation and plant communities of the Cholistan area.

The present study has confirmed and extended the previous studies on Cholistan vegetation as a whole. Arshad & Akbar (2002) had already found that different landforms have recognizable plant communities and that topography and edaphic conditions are significant; further studies indicated the significance of topography and edaphic conditions; and Naz et al. (2010, 2013) specifically showed how salinity affects species associations and spatial distribution. More recent studies around Tobas have shown the added effects of soil moisture, nutrients, and grazing pressure. The present study incorporates these ecological patterns in a habitat-wise floristic evaluation, and it has been demonstrated that sand dunes, sandy plains, shrublands, saline Dahars, drainage channels, and Toba margins support different floristic components of the region. The main contribution of the present study is not only that 58 species and 19 families were documented, but also to illustrate how this floristic diversity is partitioned between major rangeland habitats. The results support the results of the earlier studies, which came to the conclusion that together habitat heterogeneity, soil salinity, moisture availability, topography, and disturbance shape the vegetation of Cholistan. Conservation at the habitat level is more important than a focus on overall species richness for protecting this diversity and includes conservation of dune vegetation, saline communities and local moisture-dependent habitats.

The 58 recorded plant species, representing 19 families, demonstrate substantial floristic diversity under the arid and saline conditions of the Cholistan Rangelands (Arshad & Akbar, 2002). Asteraceae was the most species-rich family, while Aizoaceae, Amaranthaceae, Asclepiadaceae, Capparaceae and Chenopodiaceae were also well represented, reflecting the prevalence of drought- and salinity-tolerant taxa in the regional flora (Arshad & Akbar, 2002; Wariss et al., 2021).

Conclusions

This study is important as it shows the ecological distribution diversity of different species of the plants of the Cholistan Rangelands. The results indicate that habitat heterogeneity, soil characteristics, salinity, and local moisture availability affect vegetation composition. In order to survive in extreme dry conditions, desert plants have a variety of adaptive strategies such as drought-resistant life forms, perennial growth cycles, and seasonal life cycles. The sand dunes,

saline depressions, interdunal habitats, and areas related to Toba were recognized as significant ecological units with the support of different plant communities. The study adds to previous floristic information by incorporating species composition diversity and further distribution patterns. Preserving the diversity of habitats and important perennial vegetation is critical to ensure the ecological stability and resilience of the Cholistan Rangelands ecosystem.

Data Availability Statement

Data are available and can be received from the corresponding author on request.

Declaration of Funding

No funding was provided for this research.

Conflict of Interest

The author declares no conflict of interest.

References

Akbar, G., Rashid, S. M., & Younas, M. (1996). *Cholistan Desert: A profile*. Pakistan Council of Research in Water Resources.

Arshad, M., & Akbar, G. (2002). Benchmark of plant communities of Cholistan Desert. *Pakistan Journal of Biological Sciences, 5*(10), 1110–1113. https://doi.org/10.3923/pjbs.2002.1110.1113

Arshad, M., Salah-ud-Din, & Rao, A. R. (2002). Phytosociological assessment of natural reserve of National Park Lalsuhanra (Punjab, Pakistan). *Asian Journal of Plant Sciences, 1*(2), 174–175. https://doi.org/10.3923/ajps.2002.174.175

Austin, A. T., Yahdjian, L., Stark, J. M., Belnap, J., Porporato, A., Norton, U., Ravetta, D. A., & Schaeffer, S. M. (2004). Water pulses and biogeochemical cycles in arid and semiarid ecosystems. *Oecologia, 141*(2), 221–235. https://doi.org/10.1007/s00442-004-1519-1

Berdugo, M., Delgado-Baquerizo, M., Soliveres, S., Hernández-Clemente, R., Zhao, Y., Gaitán, J. J., Gross, N., Saiz, H., Maire, V., Lehmann, A., Rillig, M. C., Solé, R. V., & Maestre, F. T. (2020). Global ecosystem thresholds driven by aridity. *Science, 367*(6479), 787–790. https://doi.org/10.1126/science.aay5958

Bestelmeyer, B. T., Tugel, A. J., Peacock, G. L., Robinett, D. G., Shaver, P. L., Brown, J. R., Herrick, J. E., Sanchez, H., & Havstad, K. M. (2009). State-and-transition models for heterogeneous landscapes: A strategy for development and application. *Rangeland Ecology & Management, 62*(1), 1–15. https://doi.org/10.2111/08-146

Bragg, D. C. (2008). An improved tree height measurement technique tested on mature southern pines. *Southern Journal of Applied Forestry, 32*(1), 38–43. https://doi.org/10.1093/sjaf/32.1.38

Cain, S. A., & Castro, G. M. O. (1959). *Manual of vegetation analysis*. Harper & Brothers.

Colwell, R. K. (2009). Biodiversity: Concepts, patterns, and measurement. In S. A. Levin (Ed.), *The Princeton guide to ecology* (pp. 257–263). Princeton University Press. https://doi.org/10.1515/9781400833023.257

Cornelissen, J. H. C., Lavorel, S., Garnier, E., Díaz, S., Buchmann, N., Gurvich, D. E., Reich, P. B., ter Steege, H., Morgan, H. D., van der Heijden, M. G. A., Pausas, J. G., & Poorter, H. (2003). A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. *Australian Journal of Botany, 51*(4), 335–380. https://doi.org/10.1071/BT02124

Curtis, R. O., & Marshall, D. D. (2005). *Permanent-plot procedures for silvicultural and yield research* (General Technical Report PNW-GTR-634). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://doi.org/10.2737/PNW-GTR-634

Faisal, M. S., Qadir, A., & Saqib, Z. (2025). Spatio-temporal distribution of natural vegetation in Cholistan Desert concerning climate change. *Theoretical and Applied Climatology, 156*, Article 584. https://doi.org/10.1007/s00704-025-05789-1

Huang, J., Yu, H., Guan, X., Wang, G., & Guo, R. (2016). Accelerated dryland expansion under climate change. *Nature Climate Change, 6*, 166–171. https://doi.org/10.1038/nclimate2837

Jain, S. K., & Rao, R. R. (1977). *A handbook of field and herbarium methods*. Today & Tomorrow's Printers and Publishers.

Kent, M. (2012). *Vegetation description and data analysis: A practical approach* (2nd ed.). Wiley-Blackwell.

Krebs, C. J. (1999). *Ecological methodology* (2nd ed.). Benjamin/Cummings.

Larcher, W. (2003). *Physiological plant ecology: Ecophysiology and stress physiology of functional groups* (4th ed.). Springer.

Levin, S. A. (1992). The problem of pattern and scale in ecology: The Robert H. MacArthur Award Lecture. *Ecology, 73*(6), 1943–1967. https://doi.org/10.2307/1941447

Maestre, F. T., Castillo-Monroy, A. P., Bowker, M. A., & Ochoa-Hueso, R. (2012). Species richness effects on ecosystem functioning in drylands depend on plant functional diversity and habitat integrity. *Philosophical Transactions of the Royal Society B: Biological Sciences, 367*(1606), 3140–3153. https://doi.org/10.1098/rstb.2011.0200

Maestre, F. T., Eldridge, D. J., Soliveres, S., Kéfi, S., Delgado-Baquerizo, M., Bowker, M. A., García-Palacios, P., Gaitán, J., Gallardo, A., Lázaro, R., & Berdugo, M. (2016). Structure and functioning of dryland ecosystems in a changing world. *Annual Review of Ecology, Evolution, and Systematics, 47*, 215–237. https://doi.org/10.1146/annurev-ecolsys-121415-032311

Maestre, F. T., Quero, J. L., Gotelli, N. J., Escudero, A., Ochoa, V., Delgado-Baquerizo, M., García-Gómez, M., Bowker, M. A., Soliveres, S., Escolar, C., García-Palacios, P., Berdugo, M., Valencia, E., Gaitán, J., Bardgett, R. D., Reynolds, J. F., & Cortina, J. (2012). Plant species richness and ecosystem multifunctionality in global drylands. *Science, 335*(6065), 214–218. https://doi.org/10.1126/science.1215442

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing.

Mueller-Dombois, D., & Ellenberg, H. (1974). *Aims and methods of vegetation ecology*. John Wiley & Sons.

Naz, N., Hameed, M., Ashraf, M., Arshad, M., & Ahmad, M. S. A. (2010). Impact of salinity on species association and phytosociology of halophytic plant communities in the Cholistan Desert, Pakistan. *Pakistan Journal of Botany, 42*(4), 2359–2367.

Naz, N., Hameed, M., Nawaz, T., Ahmad, M. S. A., & Ashraf, M. (2013). Soil–plant relationships in the arid saline desert of Cholistan. *Arid Land Research and Management, 27*(2), 140–152. https://doi.org/10.1080/15324982.2012.719576

Noy-Meir, I. (1973). Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics, 4*, 25–51. https://doi.org/10.1146/annurev.es.04.110173.000333

Pérez-Harguindeguy, N., Díaz, S., Garnier, E., Lavorel, S., Poorter, H., Jaureguiberry, P., Bret-Harte, M. S., Cornwell, W. K., Craine, J. M., Gurvich, D. E., Urcelay, C., Veneklaas, E. J., Reich, P. B., Poorter, L., Wright, I. J., Ray, P., Enrico, L., Pausas, J. G., de Vos, A. C., . . . Cornelissen, J. H. C. (2013). New handbook for standardised measurement of plant functional traits worldwide. *Australian Journal of Botany, 61*(3), 167–234. https://doi.org/10.1071/BT12225

Rao, A. R., & Arshad, M. (1991). *Flora of the Cholistan Desert: Systematic list of trees, shrubs, and grasses*. Cholistan Institute of Desert Studies.

Rasheed, S., Khan, S. M., Ahmad, Z., Mustafa, G., Haq, Z. U., Shah, H., Ansari, L., & Jatt, T. (2022). Ecological assessment and indicator species analyses of the Cholistan Desert using multivariate statistical tools. *Pakistan Journal of Botany, 54*(2), 683–694. https://doi.org/10.30848/PJB2022-2(24)

Raunkiaer, C. (1934). *The life forms of plants and statistical plant geography*. Oxford University Press.

Reynolds, J. F., Stafford Smith, D. M., Lambin, E. F., Turner, B. L., II, Mortimore, M., Batterbury, S. P. J., Downing, T. E., Dowlatabadi, H., Fernández, R. J., Herrick, J. E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F. T., Ayarza, M., & Walker, B. (2007). Global desertification: Building a science for dryland development. *Science, 316*(5826), 847–851. https://doi.org/10.1126/science.1131634

Sala, O. E., Chapin, F. S., III, Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M., & Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *Science, 287*(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Stewart, R. R. (1972). *An annotated catalogue of the vascular plants of West Pakistan and Kashmir*. Fakhri Printing Press.

The Angiosperm Phylogeny Group. (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society, 181*(1), 1–20. https://doi.org/10.1111/boj.12385

Turner, M. G. (2005). Landscape ecology: What is the state of the science? *Annual Review of Ecology, Evolution, and Systematics, 36*, 319–344. https://doi.org/10.1146/annurev.ecolsys.36.102003.152614

Ward, D. (2016). *The biology of deserts* (2nd ed.). Oxford University Press.

Wariss, H. M., Mukhtar, M., Anjum, S., Bhatti, G. R., Pirzada, S. A., & Alam, K. (2013). Floristic composition of the plants of the Cholistan Desert, Pakistan. *American Journal of Plant Sciences, 4*(12A), 58–65. https://doi.org/10.4236/ajps.2013.412A1009

Whitford, W. G. (2002). *Ecology of desert systems*. Academic Press.

World Flora Online. (2026). *World Flora Online*. Retrieved August 21, 2026, from https://www.worldfloraonline.org/