



Plant and Soil Fungal Diversity in Semi-Arid Urban Parks: Environmental Drivers from Hyderabad, Pakistan

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Abstract

*Semi-arid areas have urban green spaces that can be classified as hotspots for biodiversity, but studies on flora and soil fungi are limited. A study was conducted using stratified quadrats to evaluate the diversity of plants and fungi in seven urban parks located in Hyderabad Cantonment, Sindh, Pakistan. Research methods included quadrat sampling to collect all specimens, culture-based methods for isolating fungi, and the determination of soil physicochemical characteristics to assess environmental conditions. The results showed that there are 105 different vascular plant species in the parks (40 species of trees, 26 species of shrubs, and 39 species of herbs). The most common vascular species include *Azadirachta indica*, *Jatropha curcas*, *Cynodon dactylon*, and *Conocarpus erectus*, with Rani Bagh ($H' = 3.47$ and $1-D = 0.93$) and Zia Uddin Park having the greatest levels of biodiversity among the parks studied. This is primarily due to tree canopies that reduce human foot traffic over time. The results of the soil study showed that these urban locations were characterized by: (1) sandy soils that were slightly alkaline (pH 8.3–8.6), (2) low levels of organic matter (0.35–0.60%), and (3) variable salinity ($EC = 0.37$ – 9.52 dS m⁻¹). Across the seven parks, several genera of fungi were identified, with *Aspergillus*, *Penicillium*, *Fusarium*, and *Trichoderma* being the most dominant in areas that still had vegetative cover. Based on our analyses, the established pattern of vegetation structure and soil texture were more important factors in determining patterns of plant and fungi diversity than park size. Conservation efforts for urban resilience and health can be enhanced by establishing trees in urban areas, increasing soil nutrients, and planting native vegetation.*

1. Introduction

Biodiversity provides essential stability to ecosystems, with plants and fungi playing a central role in nutrient cycling, habitat formation, soil development, and plant resilience through mycorrhizae and decomposition processes (Bernreiter & Teijeiro, 2022). In particular, plant–fungal interactions regulate ecosystem functioning by influencing nutrient availability, soil structure, and plant stress tolerance, making them fundamental to both natural and urban ecosystems (Malakar et al., 2024). Plants are primary producers and form the structural foundation of terrestrial ecosystems due to their abundance, diversity, and role in

energy flow (Karwal, 2026). They shape habitat heterogeneity, regulate microclimatic conditions, and influence resource availability, thereby structuring associated microbial and faunal communities. Fungi, often referred to as the “hidden kingdom,” perform key ecological functions, including the decomposition of organic matter, nutrient cycling, and nutrient transfer through mutualistic associations such as mycorrhizae. These interactions enhance plant growth, improve soil fertility, and increase resistance to environmental stresses such as drought, salinity, and nutrient limitation (Hawksworth & Lücking, 2017).

Despite their ecological importance, fungal diversity remains poorly studied, particularly in developing countries such as

Pakistan, where mycological biodiversity assessments are limited, fragmented, or outdated (Fang et al., 2023). This lack of baseline information restricts a comprehensive understanding of ecosystem functioning and constrains effective biodiversity conservation strategies.

Hyderabad, located in Sindh, Pakistan, is a semi-arid region characterized by high temperatures, low rainfall, and increasing anthropogenic pressure due to rapid urbanization and land-use change (Masood et al., 2024). Urban green spaces in this region, particularly parks, have retained portions of pre-urbanization vegetation and function as refugia for biodiversity. These areas—especially those near the Indus River—serve as remnant habitats that support plant and fungal diversity within a highly modified urban landscape. Their composition is influenced by habitat age, structural complexity, irrigation practices, and edaphic factors, which also contribute to insect diversity and overall ecosystem stability (Ali et al., 2020).

Urbanization has been broadly linked to the loss of biodiversity and simplification of ecosystems, such as the reduction of fungal richness in soil and air, as well as the replacement of specialized species by more generalist ones that are resistant to pollution and habitat homogenization (Abrego et al., 2020; Lin et al., 2021). Nevertheless, fungi are also essential in enhancing plant drought resistance and ecosystem resilience, especially in semi-arid areas where water availability is limited. As a result, urban green areas serve as significant biodiversity reservoirs and important ecosystems that contribute to environmental quality and human well-being (CBD, 2020).

An integrated understanding of plant and fungal communities, including their ecological roles and potential applications, is essential for sustainable urban ecosystem management (Purahong et al., 2022). The maintenance of urban plant diversity contributes to ecological resilience, habitat heterogeneity, ecosystem service provision, and the long-term sustainability of urban environments, along with associated socio-economic benefits (Pandey & Ghosh, 2023).

In Pakistan, urban biodiversity research has predominantly focused on vegetation, while fungal diversity and its functional roles remain largely overlooked (Talal et al., 2025). This represents a critical knowledge gap, particularly in understanding plant–fungal interactions in urban ecosystems. Therefore, the present study aims to characterize plant–fungal communities in urban green spaces of Hyderabad, identify dominant plant species and associated soil fungi, and examine the abiotic factors influencing their interactions. It also evaluates fungal functional groups and their ecological roles. The findings will contribute to urban biodiversity research by generating baseline data to support conservation planning and improve understanding of the

ecological and economic significance of plant and fungal diversity in semi-arid urban environments.

2. Materials and Methods

2.1. Study Area

Maturity, management practices, and recreational use are the key aspects that define the parks of Hyderabad Cantonment. The parks included in this study—Rani Bagh, Zia Uddin Park, Defense Park, and the Sports Ground (Table 1)—differ in vegetation maturity, management inputs, and intended use (Figure 1).

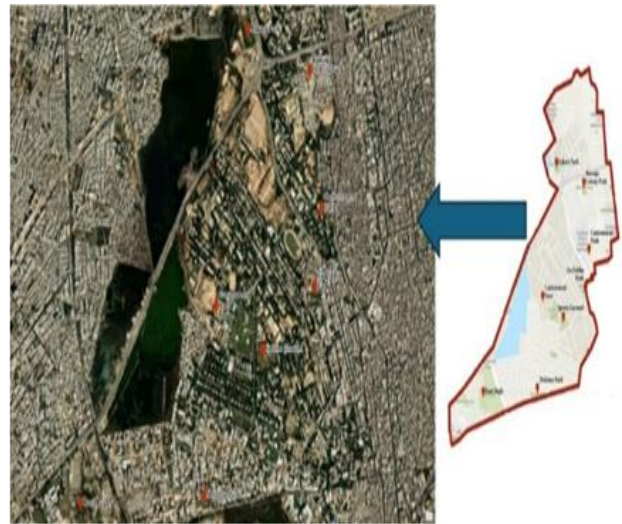


Figure 1. Site map of Cantonment Area, Hyderabad, Sindh

2.2. Vegetation Sampling

The stratified quadrat method was used for vegetation sampling. Besides, the individual parks were the locations chosen for this technique and the entire area of the cantonment was selected as the study area (Figure 2). The parks were divided into three height layers: the tree layer, the shrub layer, and the herbaceous layer. Floristic assessment protocols were strictly followed (Sun & Jing, 2025; Min & Pan, 2022), where the same-sized quadrats for each height layer were set up. Plant species lists (Table 2–4) derived from quadrat inventories (trees: 10×10 m, n=10; shrubs: 5×5 m, n=25; herbs: 1×1 m, n=100 per park) (Figure 3–4), with life forms classified per Raunkiaer system and IUCN status from IUCN Red List. In each park, ten quadrats were laid down for each vegetation layer. However, they were placed randomly to capture spatial heterogeneity and to minimize edge effects (Loke & Chisholm, 2022). Between June to September 2024, the time of flowering and hence maximum growth for most plants, identification of species was done easily (Min & Pan, 2022). Mostly each quadrat contained various plant species which were recorded and also the data of the species

composition and abundance were collected. For the tree and shrub layers, the number of individuals was counted, while in the herbaceous vegetation the frequency and presence-absence data were recorded because of the high density and small size of plants (Boz & Maryo, 2020). Each park layer of vegetation was calculated for relative abundance and life-form composition. The species identification was verified with the help of standard floras and authoritative botanical databases (Li et al., 2024).

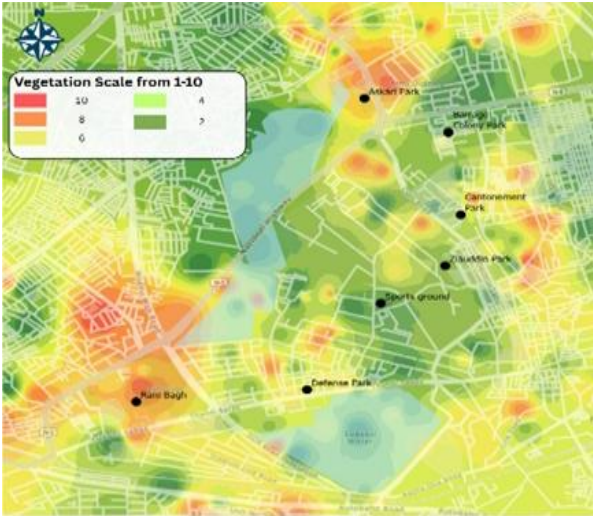


Figure 2. Vegetation map of Cantonment Area, Hyderabad, Sindh

2.3 Diversity Indices

Species diversity was evaluated using the Shannon–Wiener diversity index (H') and the Simpson diversity index (D) (Shannon, 1948; Simpson, 1949). The Shannon–Wiener index was calculated using the following formula:

$$H' = -\sum (pi \ln pi)$$

where pi represents the proportion of individuals of the i th species relative to the total number of individuals in each area or location. This index provides a combined measure of species richness and evenness (Gatti et al., 2020). The Simpson diversity index was calculated using the following formula:

$$D = 1 - \sum (pi^2)$$

where pi represents the proportional abundance of each species. This index gives greater weight to dominant species and estimates the probability that two randomly selected individuals belong to different species (Roswell et al., 2021; Kitikidou et al., 2024). To facilitate comparison of plant diversity patterns among sites, both indices were calculated separately for each vegetation layer and each park.

2.4. Soil Physicochemical Analysis

The soil physicochemical properties that affected the fungal communities were established using composite samples of the top layer of soil (0–15 cm depth) from each park. Typical analytical procedures were applied, such as determination of soil texture by the feel method, determination of pH and electrical conductivity ($dS\ m^{-1}$) of the soil by 1:2 soil-water suspension, estimation of the organic matter (percent) of the soil by the Walkley–Black wet digestion procedure, and determination of total nitrogen (percent) by the Kjeldahl digestion procedure (Table 1).

Table 1. Soil physicochemical characteristics of study sites in Hyderabad Cantonment parks

Site location	UTM Coordinates	Elevati on	Depth	Soil Type	Soil Texture	(EC)d s/m	pH(ds /m)	OM (%)	N (%)
Askari park	25°24'26.99"N68°2 1'21.68"E	23m	0-6 inches	Saline	Sandy soil	9.52	8.4	0.39	0.020
Barrage colony park	25°24'18.31"N68°2 1'40.70"E	24m	0-6 inches	Non- Saline	Sandy soil	0.37	8.5	0.60	0.030
Cantonment Park	25°23'32.54"N68°2 1'18.45"E	25m	0-6 inches	Non- Saline	Sandy soil	0.69	8.3	0.37	0.018
Defense Park	25°23'3.52"N68°21' 5.68"E	20m	0-6 inches	Non- Saline	Sandy soil	0.48	8.6	0.52	0.026
Rani Bagh	25°22'59.05"N68°2 0'17.65"E	17m	0-6 inches	Non- Saline	Sandy soil	0.5	8.5	0.35	0.018
Sports ground	25°23'29.27"N68°2 1'25.99"E	27m	0-6 inches	Non- Saline	Sandy soil	0.73	8.3	0.60	0.030
Ziauddin Park	25°23'40.09"N68°2 1'42.40"E	29m	0-6 inches	Non- Saline	Sandy soil	1.24	8.5	0.52	0.026

Table 2. Herb species recorded in the Cantonment parks of Hyderabad, Sindh, Pakistan, including local names, families, growth habits, life forms, and IUCN conservation status

Name of species	Family	Number of species	Common name	Habitat	Life form	IUCN Category
<i>Cynodon dactylon</i>	Poaceae	39	Common grass	H	P	DD
<i>Digitaria ciliaris</i>	Poaceae	2	Southern crabgrass	H	A	LC
<i>Cenchrus clandestinus</i>	Poaceae	4	Kikuyu grass	H	P	DD
<i>Cyperus rotundus</i>	Poaceae	5	Nut grass/lemon grass	H	P	LC
<i>Muhlenbergia schreberi</i>	Poaceae	5	Dropseed/Nimble weed	H	P	DD
<i>Panicum repens</i>	Poaceae	1	Torpedo grass	H	P	LC
<i>Hemarthria altissima</i>	Poaceae	1	Limpo grass	H	P	DD
<i>Phragmites australis</i>	Poaceae	5	Common reed	H	P	LC
<i>Axonopus compressus</i> (Sw.) P.Beauv.	Poaceae	1	Tropical carpet grass	H	P	NE
<i>Eleusine indica</i>	Poaceae	2	Indian goosegrass	H	A	LC
<i>Portulaca grandiflora</i> Hook.	Portulacaceae	7	Moss-rose purslane	H	A	LC
<i>Euphorbia hirta</i>	Euphorbiaceae	4	Asthma plant	H	A	LC
<i>Tribulus terrestris</i>	Zygophyllaceae	3	Puncture vine	H	A	LC
<i>Hieracium gronovii</i>	Asteraceae	1	Hairy hawkweed	H	P	DD
<i>Citrullus colocynthis</i>	Cucurbitaceae	1	Bitter apple	H	P	LC
<i>Cicuta maculata</i> (group)	Apiaceae	1	Water hemlock	H	P	DD
<i>Crepis capillaris</i>	Asteraceae	3	Smooth hawksbeard	H	A	LC
<i>Carex muskingumensis</i>	Cyperaceae	3	Palm sedge	H	P	DD
<i>Lactuca serriola</i>	Asteraceae	7	Prickly lettuce	H	A/B	LC
<i>Paspalum notatum</i>	Poaceae	4	Bahia grass	H	P	LC
<i>Catharanthus roseus</i> L.	Apocynaceae	10	Pink periwinkle	H/S.Shrub	P	EN
<i>Astelia nervosa</i>	Asteliaceae	5	Mountain astelia	H	P	NE
<i>Asparagus densiflorus</i>	Asparagaceae	1	Foxtail fern	H	P	LC
<i>Alternanthera dentata</i>	Amaranthaceae	3	Joseph's coat	H	P	DD
<i>Impatiens glandulifera</i>	Balsaminaceae	1	Himalayan balsam	H	A	INV
<i>Trianthema portulacastrum</i>	Aizoaceae	4	Desert horse purslane	H	A	DD
<i>Phormium tenax</i>	Asphodelaceae	1	New Zealand flax	H	P	DD
<i>Ipomoea batatas</i>	Convolvulaceae	1	Sweet potato	H	P	DD
<i>Ibicella lutea</i>	Martyniaceae	2	Yellow unicorn plant	H	A	DD
<i>Epilobium tetragonum</i>	Onagraceae	1	Square-stalk willow herb	H	P	NE
<i>Nemesia strumosa</i>	Scrophulariaceae	2	Cape jewels	H	A/P	NE
<i>Eclipta alba</i>	Asteraceae	1	False daisy	H	A	LC
<i>Sesbania bispinosa</i>	Fabaceae	2	Danchi	H	A/B	LC
<i>Cyperus erythrorhizos</i>	Cyperaceae	2	Red-rooted sedge	H	P	EX (Regional)
<i>Launaea procumbens</i>	Asteraceae	1	Creeping launaea	H	P	DD
<i>Euphorbia prostrata</i>	Euphorbiaceae	3	Prostrate sandmat	H	A	LC

(H= herb; FH= flowering herb; S-Sh=sub-shrub; WH= woody herb; P= perennial; A= annual; B= biennial; DD= data deficient; LC= least concern; EN= endangered; VU= vulnerable; NE= not evaluated)

Table 3. Shrub species recorded in the Cantonment parks of Hyderabad, Sindh, Pakistan, including local names, families, growth habits, life forms, and IUCN conservation status

Name of species	Family	Number of species	Common name	Habitat	Life form	IUCN Category
<i>Jasminum sambac</i> L.	Oleaceae	1	Arabian jasmine	Sh	P	DD
<i>Conocarpus erectus</i>	Combretaceae	14	Buttonwood / button mangrove	Sh	P	LC
<i>Laurus nobilis</i>	Lauraceae	5	Bay laurel	L.Sh/T	P	S
<i>Hibiscus rosa-sinensis</i>	Malvaceae	7	Chinese hibiscus	Sh	P	DD
<i>Ixora coccinea</i>	Rubiaceae	7	Jungle geranium	Sh	P	EN
<i>Convolvulus creticus</i>	Convolvulaceae	2	Littoral bindweed	S.Sh	P	S
<i>Manihot esculenta</i>	Euphorbiaceae	2	Cassava	Sh	P	S
<i>Jatropha curcas</i>	Euphorbiaceae	10	Physic nut / Barbados nut	S/ST	P	S
<i>Euphorbia milii</i>	Euphorbiaceae	7	Crown-of-thorns	Sh	P	LC
<i>Calotropis gigantea</i>	Apocynaceae	5	Giant calotrope	Sh	P	DD
<i>Abutilon mauritianum</i> Jacq.	Malvaceae	1	African mallow	Sh	P	DD
<i>Abutilon palmeri</i>	Malvaceae	4	Palmer’s Indian mallow	Sh	P	DD
<i>Prosopis juliflora</i>	Fabaceae	1	Mesquite / Kabuli keekar	Sh/ST	P	INV
<i>Ziziphus nummularia</i>	Rhamnaceae	1	Wild jujube / jharberi	Sh	P	LC
<i>Plumeria pudica</i>	Apocynaceae	2	Bridal bouquet	Sh	O	LC
<i>Muehlenbeckia australis</i>	Polygonaceae	3	Shrubby creeper	Sh	P	EN
<i>Ficus microcarpa</i>	Moraceae	2	Chinese banyan	Sh/T	P	LC
<i>Carissa macrocarpa</i>	Apocynaceae	4	Natal plum	Sh	P	LC
<i>Genista tinctoria</i>	Fabaceae	1	Dyer’s greenweed	Sh	P	DD
<i>Lonicera japonica</i>	Caprifoliaceae	2	Japanese honeysuckle	H	P	INV
<i>Ricinus communis</i>	Euphorbiaceae	1	Castor bean	S/ST	P	LC
<i>Rosa multiflora</i>	Rosaceae	2	Baby rose	Sh	P	DD
<i>Guaiacum officinale</i>	Zygophyllaceae	1	Guaiac wood	Sh	P	EN
<i>Nerium oleander</i>	Apocynaceae	2	Oleander	Sh/ST	P	LC
<i>Breynia disticha</i>	Phyllanthaceae	2	Snowbush	S/ST	O/C	DD
<i>Cestrum nocturnum</i>	Solanaceae	1	Night-blooming jasmine	Sh	O	LC
<i>Hibiscus schizopetalus</i>	Malvaceae	3	Spider hibiscus	Sh	P	NE

(H=herb, FH=Flowering herb, S-Sh=Sub-shrub, WH=Woody Herb, P=Perennial, A=Annual, B=Biennial, DD= Data Deficient, S= Shrub, L.sh=Large shrub, ST=Small tree, O=Ornamental)

2.5. Isolation, Enumeration, and Identification of Fungi

The fungi in soil were isolated by using the serial dilution plate technique. In a nutshell, the air-dried composite soil (10 g) was suspended in 90 mL of sterile water and mixed by shaking for 20–30 min. Ten-fold dilutions were taken to 10⁻⁴ or 10⁻⁵ and 1 mL of the aliquots was plated on Potato

Dextrose Agar (PDA) with streptomycin (50 mg L⁻¹) to prevent bacterial growth (Tables 5-6). All dilutions were prepared in triplicates to make it accurate and reproducible. Plates were incubated at 25°C in an inverted position under dark conditions with observation of fungal growth for 5–7 days (Table 7).

Table 4. Tree species recorded in the Cantonment parks of Hyderabad, Sindh, Pakistan, including local names, families, growth habits, life forms, and IUCN conservation status

Name of species	Family	Number of species	Common name	Habitat	Life form	IUCN Category
<i>Albizia adianthifolia</i>	Fabaceae	1	Flat crown albizia	T	O/C	LC
<i>Azadirachta indica</i>	Meliaceae	9	Neem	T	P	LC
<i>Bismarckia nobilis</i>	Arecaceae	1	Bismarck palm	T	P	DD
<i>Borassus aethiopum</i>	Arecaceae	1	African fan palm	T	P	LC
<i>Brahea armata</i>	Arecaceae	1	Mexican blue palm	T	P	LC
<i>Breynia disticha</i>	Phyllanthaceae	2	Snowbush	Sh/ST	O/C	DD
<i>Cordia myxa</i>	Boraginaceae	1	Assyrian plum	Sh/ST	P	LC
<i>Cordyline australis</i>	Asparagaceae	4	Cabbage tree	T	P	S
<i>Cycas revoluta</i>	Cycadaceae	4	Japanese sago palm	T	P	LC
<i>Eucalyptus camaldulensis</i>	Myrtaceae	1	River red gum	T	P	NT
<i>Eucalyptus rubida</i>	Myrtaceae	1	Candle bark gum	T	P	NT
<i>Ficus benjamina</i>	Moraceae	3	Weeping fig	T	O/C	LC
<i>Ficus microcarpa</i>	Moraceae	2	Chinese banyan	Sh/T	P	LC
<i>Ficus rubiginosa</i>	Moraceae	1	Rusty fig	T	P	LC
<i>Heritiera littoralis</i>	Malvaceae	1	Tulip mangrove	T	P	LC
<i>Hyophorbe indica</i>	Arecaceae	1	Palmiste palm	T	O/C	EN
<i>Iris chinensis</i>	Iridaceae	3	Blackberry lily	T	O/C	EN
<i>Jatropha curcas</i>	Euphorbiaceae	10	Physic nut	Sh/ST	P	S
<i>Laurus nobilis</i>	Lauraceae	5	Bay laurel	Sh/T	P	S
<i>Lawsonia inermis</i>	Lythraceae	4	Henna	Sh/ST	P	LC
<i>Livistona chinensis</i>	Arecaceae	1	Chinese fan palm	T	P	I
<i>Manilkara zapota</i>	Sapotaceae	2	Sapodilla	T	P	LC
<i>Moringa oleifera</i>	Moringaceae	2	Moringa	T	P/A	LC
<i>Murraya koenigii</i>	Rutaceae	1	Curry leaf tree	T	P	DD
<i>Nerium oleander</i>	Apocynaceae	2	Oleander	Sh/ST	P	LC
<i>Phoenix dactylifera</i>	Arecaceae	1	Date palm	T	C	S
<i>Phoenix roebelenii</i>	Arecaceae	5	Pygmy date palm	ST	P	DD
<i>Plerandra veitchii</i>	Araliaceae	2	False aralia	H/ST	P	LC
<i>Plumeria rubra</i>	Apocynaceae	1	Frangipani	ST	P	DD
<i>Pongamia pinnata</i>	Fabaceae	2	Pongame oil tree	T	P	LC
<i>Prosopis juliflora</i>	Fabaceae	1	Mesquite	Sh/ST	P	INV
<i>Ricinus communis</i>	Euphorbiaceae	1	Castor bean	Sh/ST	P	HI
<i>Roystonea regia</i>	Arecaceae	1	Royal palm	T	P	LC
<i>Satakentia liukiuensis</i>	Arecaceae	1	Satake palm	T	O	S
<i>Syzygium cumini</i>	Myrtaceae	2	Jamun	T	P	LC
<i>Terminalia catappa</i>	Combretaceae	1	Tropical almond	T	P	LC
<i>Terminalia ivorensis</i>	Combretaceae	1	Black afara / brimstone wood	T	C	V
<i>Thuja occidentalis</i>	Cupressaceae	6	Northern white cedar	T	P	S
<i>Tipuana tipu</i> Benth.	Fabaceae	1	Tipu / rosewood	T	O/C	LC

<i>Ziziphus lotus</i>	Rhamnaceae	3	Lotus tree / wild jujube	T/H	P	DD
<i>Volkameria inermis</i>	Lamiaceae	1	Glory bower / seashore clerodendrum	Sh/T	C/W	NE
<i>Cryptolepis buchananii</i>	Apocynaceae	1	Wax-leaved climber	Sh/T	C	DD
<i>Ficus aurea</i>	Moraceae	1	Florida strangler fig / golden fig	T	P	LC

(H=herb, FH=Flowering herb, S-Sh=Sub-shrub, WH=Woody Herb, P=Perennial, A=Annual, B=Biennial, DD= Data Deficient, S=shrub)

The number of fungal colonies after incubation was counted to establish the colony-forming units per gram of dry soil (CFU g⁻¹). Pure cultures were obtained by subculture of distinct colonies on fresh PDA plates. The purification was done either by hyphal tip transfer or by single-spore isolation methods (Figure 5a-h). The identification of fungi was done using both macroscopic and microscopic features. Colony growth rate, colony color, colony texture, colony margin, and colony pigmentation were the macroscopic features and hyphal structure, septation, conidiophores, conidia, and arrangement of the spores were the microscopic features. Lactophenol cotton blue staining was used to perform microscopic observations. Identification was done to genus and, where available, to species level by the use of standard taxonomic keys and descriptions (Zahran et al., 2022; Abbasi, 2025). Culture-based enumeration gives a semi-quantitative estimate of fungal abundance and community composition. Even though this technique mainly identifies fast-growing and sporulating fungi, nonetheless, it provides a valid and comparable measure of soil fungal communities in varied habitats (Senanayake et al., 2020).

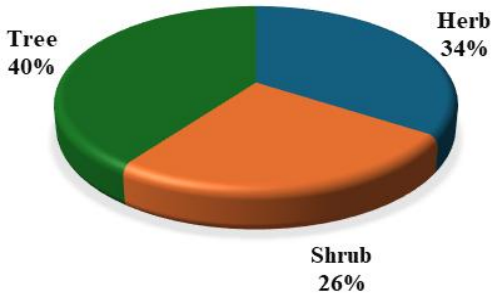


Figure 3. Relative abundance of major plant life forms in Hyderabad Cantonment, Pakistan

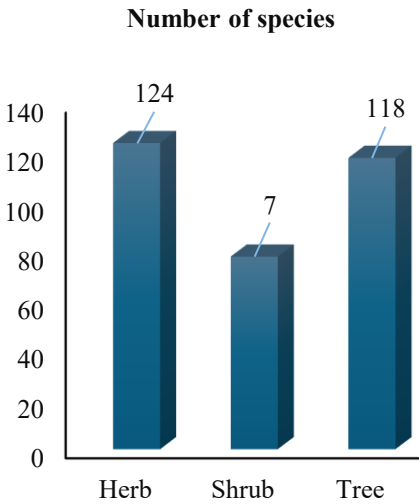


Figure 4. Comparative species richness among herbs, shrubs, and trees in the study area.

2.6. Data Analysis

The vascular plant and soil fungal communities were studied independently to determine the patterns of species richness, evenness, and community structure of the different study sites. To examine the relationship between biological diversity and environmental conditions, initial correlations between measures of diversity and physicochemical characteristics of the soil (i.e., soil texture, soil pH, and soil organic matter) were described narratively. Correlation tests were also undertaken to establish how strong and directional these relationships were in cases where the number of sampling units was large enough to enable statistical significance testing. In addition, cross-site comparisons were also undertaken in terms of several parameters, such as spatial variation in species richness, evenness, and dominant plant and fungal taxa.

Figure 5. Microscopic views of soil fungi showing hyphae and reproductive structures, including conidiophores, sporangia, and perithecia

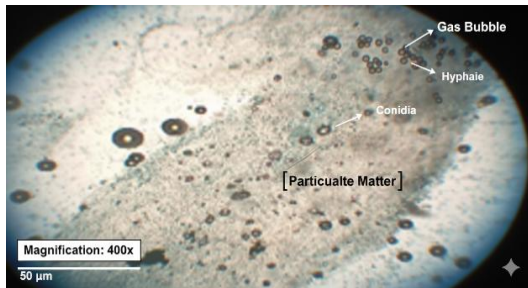


Figure 5a. Microscopic image of *Aspergillus japonicus*

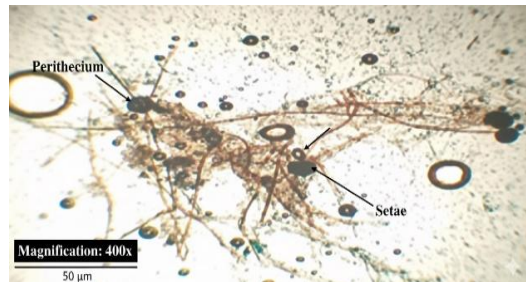


Figure 5b. Microscopic image of *Aspergillus flavus*

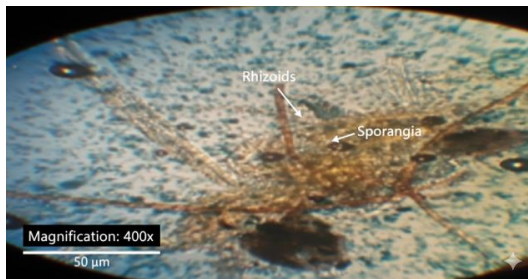


Figure 5c. Microscopic image of *Aspergillus fumigatus*

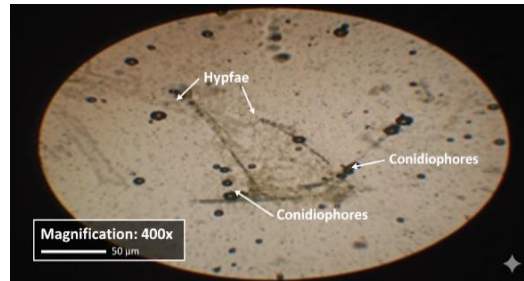


Figure 5d. Microscopic image of *Trichoderma viride*

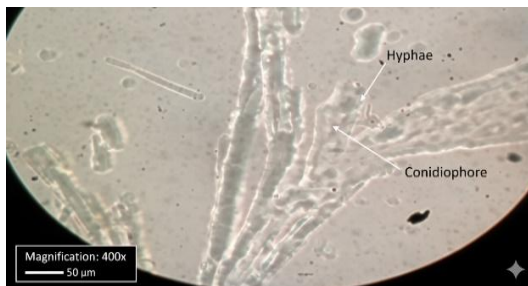


Figure 5e. Microscopic image of *Aspergillus flavus*

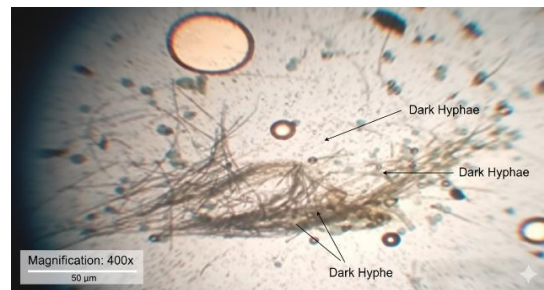


Figure 5f. Microscopic image of *Aspergillus niger*

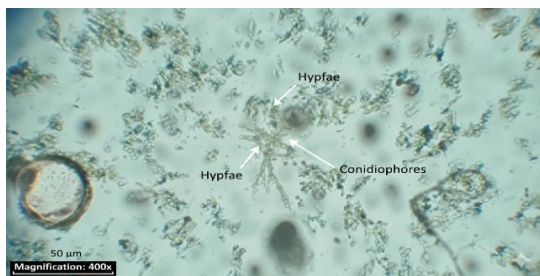


Figure 5g. Microscopic image of *Trichoderma viride*

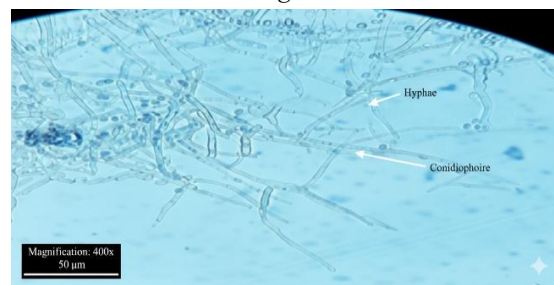


Figure 5h. Microscopic image of *Aspergillus flavus*

Table 5. Identification of soil fungi from Cantonment parks of Hyderabad, Sindh, Pakistan, based on colony morphology and microscopic characteristics

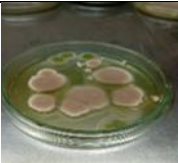
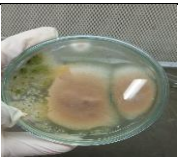
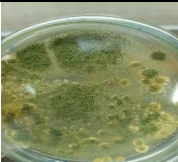
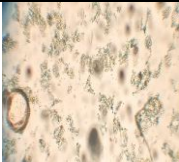
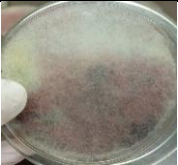
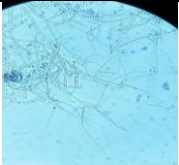
Sample code	Colony margin	Colony description	Physical appearance	Microscopic appearance	Microscopic description	Identity
FC-001	Smooth	Cottony white			Hyphae and sclerotia	<i>Aspergillus japonica</i>
FC-002	Smooth	Brownish white fluffy			Dark hair structure (setae) surrounding fruiting body (perithecium)	<i>Aspergillus flavus</i>
FC-003	Smooth	Brownish green, White fluffy			Sporangia and rhizoids	<i>Aspergillus fumigatus</i>
FC-004	Smooth	Green cottony			Hyphae and conidiophores	<i>Trichoderma viride</i>
FC-005	Smooth	Greenish brown cottony			Hyphae and conidiophores	<i>Aspergillus flavus</i>
FC-006	Smooth	Fluffy gray/black colony			Dark colored hyphae	<i>Aspergillus niger</i>
FC-007	Smooth	Yellow Greenish Colony			Hyphae and conidiophores	<i>Aspergillus flavus</i>
FC-008	Smooth	Whitish green fluffy			Hyphae and conidiophores	<i>Trichoderma viride</i>

Table 6. Fungal Counts and Morphological Characteristics of Colonies from Soil Samples from Different Locations

Sr. No.	Soil Source/Sample	Total Count ($\times 10^5$)	Dominant Cultural Characteristics		
			Shape of Colony	Edge	Color
1	Soil from Askari Park	i- 2×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 6×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 1.4×10^5	Round	Smooth	White, cream, yellow, black, brown and green
2	Soil from Barrage Colony Park	i- 1.2×10^3	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 5.8×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 1.2×10^5	Round	Smooth	White, cream, yellow, black, brown and green
3	Soil from Cantonment Park	i- 2.5×10^3	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 8×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 1×10^5	Round	Smooth	White, cream, yellow, black, brown and green
4	Soil from Defense Park	i- 2.5×10^3	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 2.2×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 8×10^4	Round	Smooth	White, cream and green
5	Soil from Rani Bagh	i- 1.6×10^3	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 4×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 2.4×10^5	Round	Smooth	White, cream, yellow, black, brown and green
6	Soil from Sports Ground	i- 3×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 2.5×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 1×10^6	Round	Smooth	White, cream, yellow, black, brown and green
7	Soil from Ziauddin Park	i- 2.6×10^3	Round	Smooth	White, cream, yellow, black, brown and green
		ii- 1.2×10^4	Round	Smooth	White, cream, yellow, black, brown and green
		iii- 5×10^5	Round	Smooth	White, cream, yellow, black, brown and green

Table 7. Shannon-Wiener (H') and Simpson (1-D) diversity indices for plant communities across Cantonment parks

Location	Shannon Index (H')	Simpson's Index (1-D)
Rani Bagh	3.47	0.93
Zia Uddin Park	3.26	0.91
Cantonment Park	2.89	0.88
Askari Park	2.81	0.85
Barrage Colony Park	2.75	0.83
Sports Ground	2.61	0.81
Defense Park	2.49	0.79

H' measures species richness and evenness; **1-D** measures probability of two random individuals from different species.

3. Results

3.1. Floristic Composition

The survey produced 105 species of vascular plants in the form of trees (40%), herbs (34%), and shrubs (26%). The commonest ones were *Azadirachta indica*, *Jatropha curcas*, *Conocarpus erectus*, *Prosopis juliflora*, *Cynodon dactylon*, and *Parthenium hysterophorus*. Rani Bagh and Zia Uddin Park had the highest Shannon and Simpson diversity indices, meaning that they had higher species diversity and evenness than other sites. Conversely, Defense Park and the Sports Ground were less diverse, which was linked with a reduced vegetation structure and a predominance of turf grasses and ruderal herbs.

3.2. Soil Properties

The park soils were sandy to sandy loam soils with slightly alkaline pH (8.3–8.6), low organic matter, and medium salinity, which is characteristic of semi-arid urban soils. The

variation in soil properties among the parks was linked to irrigation methods, litter content, and location-specific management. The organic matter of soil and soil layers in Rani Bagh and Zia Uddin Park were relatively high and less disturbed than in other parks.

3.3. Fungal Communities

Fungal communities were dominated by genera commonly found in dry and disturbed habitats, including *Aspergillus*, *Penicillium*, *Fusarium*, *Trichoderma*, and *Rhizopus*. Sites with higher litter deposition and denser canopy cover supported greater colony-forming units (CFUs) and higher genus-level diversity. Rani Bagh and Zia Uddin Park showed the highest fungal diversity among the studied sites.

3.4. Environmental Drivers of Diversity

Variations in floristic and fungal diversity were associated with habitat age, soil physicochemical characteristics, and vegetation structure. Higher vegetation cover, multi-layered canopy structure, and increased soil organic matter were associated with higher diversity indices. Park area showed no consistent relationship with biodiversity patterns. Vegetation structure and soil texture were identified as key factors influencing the composition of both plant and fungal communities.

4. Discussion

Our results demonstrate that, in semi-arid urban ecosystems, patterns of biodiversity are strongly mediated by habitat structure and soil characteristics, a pattern increasingly reported in contemporary urban ecology literature. Mature trees, multilayered vegetation, and litter retention are associated with higher plant diversity and more diverse fungal assemblages, likely because complex vegetation structures ameliorate microclimatic extremes and enhance moisture retention and resource availability for both plant and soil organisms (Rega Brodsky et al., 2022).

The impacts of these buffering mechanisms are especially important in semi-arid areas, where high air temperatures due to heat stress and the inconsistent distribution of natural precipitation favor drought-resistant and stress-tolerant species but limit slower-growing, habitat-specialist species. In this context, urban vegetation structure acts as a biotic filtering mechanism that determines which plant and fungal lineages can grow and persist (Diamant et al., 2025).

This study examined heavily developed areas where *Cynodon dactylon* and *Parthenium hysterophorus* are the prominent species, managed through mowing, irrigation, and soil compaction. These species are well known to be stress-tolerant and adapted to disturbance, characteristics typical of urban environments with intensive management that promote ruderal or fast-growing species at the expense of those with

more specific habitat requirements (Cardinal De Casas et al., 2025). Conversely, sites with larger tree canopies and greater woody litter exhibited higher plant diversity and more heterogeneous fungal community structures, indicating that reduced disturbance and increased canopy retention enhanced both compositional and functional diversity of urban vegetation. This is consistent with previous research in other semi-arid and Mediterranean urban regions, where mixed tree–shrub patches and remnant vegetation support higher plant and soil biodiversity than intensively managed lawns (Ramírez Rojas et al., 2020).

Fungal composition showed a higher abundance of *Aspergillus* and *Penicillium* in low-organic-matter, compacted urban soils, while *Trichoderma* and other saprophytic fungi were more abundant in soils with higher organic matter content. This supports the idea that urbanization favors opportunistic, generalist fungal taxa. In dryland urban soils, compaction and low nutrient availability narrow fungal niches to fast-growing, desiccation-tolerant species capable of utilizing transient organic resources. The addition of organic matter through litter retention increases fungal abundance and diversity, particularly taxa involved in nutrient cycling, consistent with findings from other dryland systems where higher soil organic matter leads to increased fungal richness and functional redundancy in urban and semi-natural ecosystems (Wang et al., 2023).

Mechanistically, our results provide evidence for a feedback loop between vegetation complexity and biodiversity–multifunctionality in semi-arid urban soils. More complex vegetation increases litter input to the soil surface, which in turn enhances fungal diversity and promotes faster decomposition and nutrient recycling (Zhang et al., 2023). Recent syntheses indicate that in dryland ecosystems, soil fungal diversity and saprotrophic richness become increasingly important drivers of ecosystem multifunctionality under high aridity, particularly when plant diversity is limited. In our study area, higher plant diversity corresponds to increased litter input, greater saprotrophic fungal diversity, and a higher likelihood of enhanced ecosystem multifunctionality.

This study does acknowledge that culture-based approaches to fungi have their limitations, namely that they preferentially select fast-growing, culturable fungi, and that they are incapable of detecting slow-growing or unculturable groups; however, this is a long-known weakness in soil microbial ecology. It emphasizes the necessity of molecular methods like DNA metabarcoding, which can identify the entire range of diverse urban fungi (Banchi et al., 2020). Molecular methods would also give information on functional guilds and symbiotic interactions that cannot be accurately measured by culture-based methods, such as mycorrhizal and

pathogenic fungi, which are of importance to plant health and ecosystem processes. Besides this, long-term seasonal sampling studies are required to decouple temporal variation and management effects especially in semi-arid areas that exhibit high precipitation variability (Barthwal et al., 2025).

Overall, the results of the present study suggest that management intensity and vegetation structure are among the most important predictors of biodiversity in urban semi-arid settings, which is why the size of a park alone is not a crucial factor. The high frequency of mowing, irrigation, and soil compaction are all forms of intensive management that result in homogenized habitats that support only a few disturbance-adapted species (Jentsch et al., 2022). Conversely, less disturbed regions with intact canopy cover and litterfall offer heterogeneous microhabitats to sustain a variety of plant-fungal communities. This is consistent with more general guidelines of urban conservation science, which argue that it is necessary to shift the emphasis from simple area- or species-based indicators to management processes, soil-plant-fungal interactions, and long-term monitoring to maintain biodiversity and ecosystem functioning under the ever-increasing pressures of aridification and urbanization.

5. Conclusion

Plant (flora) and fungal diversity is high in different parts of the Hyderabad Cantonment that are categorized as parks. Nevertheless, the most diverse flora and fungi are supported by park types with mature trees, a multilayered structure, and a greater proportion of soil organic matter. It was also observed that biodiversity patterns were strongly linked to soil conditions, structural complexity of the habitat, and management practices rather than just park area. The results indicate the significance of having diverse types of habitats and ensuring that the soils are in suitable condition to support ecosystem functioning in semi-arid urban areas. Parks containing a relatively even distribution of vegetation, little disturbance, and well-established tree cover (like Rani Bagh and ZiaUddin Park) illustrate the importance of mature habitat structure in sustaining diverse ecological communities. Thus, to achieve successful conservation of plant and fungal diversity in semi-arid urban ecosystems, management practices that balance ecology with recreational and aesthetic use of parks are necessary. Besides mature trees, multilayered vegetation (i.e., shrub, understory, and overstorey) formation and the use of drought-resistant native plant species can help stabilize habitats, enhance soil quality, and increase microbial diversity.

The application of suitable horticultural measures, including litter and mulch preservation and minimal soil disturbance, can improve soil organic matter, nutrient cycling, and ecological resilience. However, the reduction of intensive human activities, including overgrazing and mowing, is

critical for maintaining habitat complexity and supporting the coexistence of plant and fungal species. Routine monitoring of soil properties, vegetation cover, and biodiversity indicators should be part of regular park management to support evidence-based decision-making. Such a strategy will increase the ability of urban green areas to provide ecosystem services such as carbon sequestration, urban cooling, and wildlife habitat provision. In general, these measures can sustain ecologically stable landscapes, enhance resilience to environmental pressures, and contribute to the long-term sustainability of urban ecosystems in arid areas. The overall finding of this research is that habitat quality, structural diversity, and soil management are more important for urban biodiversity conservation than park size.

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8. Conflict of Interest

The authors declare no conflict of interest.

9. Authors' Contribution

Imssa Irfan conceived and designed the study, conducted the fieldwork, and performed data collection, laboratory work, and data analysis. The manuscript was prepared by Imssa Irfan, while Hadi Bux and Sikandar Ali contributed to the critical review and editing of the manuscript. All authors read and approved the final manuscript.

10. SDGs Addressed

This research supports the UN's 2030 Agenda for Sustainable Development and specifically contributes to Sustainable Development Goal (SDG) 11, focus area A, by documenting how green spaces within cities improve biodiversity and stimulate ecosystem resilience in regions with semi-arid climates. It also supports SDG 15 through the monitoring and conservation of both plant and soil fungal diversity, reinforcing that ecosystem functions and soil health need to be maintained.

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