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Community Structure and Distribution Pattern of Woody Vegetation in Response to Soil properties in Semi-Arid Lowland District Kasur Punjab, Pakistan

Muhammad Waheed [1], Fahim Arshad [1], Muhammad Majeed [2], Sammer Fatima [2], Naila Mukhtar [1], Robina Aziz [3], Wali Muhammad Mangrio [4], Hussein Almohamad [5,*], Ahmed Abdullah Al Dughairi [5], Motrih Al-Mutiry [6] and Hazem Ghassan Abdo [7,8,9]

1 Department of Botany, University of Okara, Okara 56300, Pakistan
2 Department of Botany, University of Gujrat, Hafiz Hayat Campus, Gujrat 50700, Pakistan
3 Department of Botany, Government College, Women University, Sialkot 51310, Pakistan
4 Department of Zoology, Faculty of Natural Sciences, Shah Abdul Latif University, Khairpur 66111, Pakistan
5 Department of Geography, College of Arabic Language and Social Studies, Qassim University, Buraydah 51452, Saudi Arabia
6 Department of Geography, College of Arts, Princess Nourah Bint Abdulrahman University, Riyadh 11671, Saudi Arabia
7 Geography Department, Faculty of Arts and Humanities, University of Tartous, Tartous P.O. Box 2147, Syria
8 Geography Department, Faculty of Arts and Humanities, Damascus University, Damascus P.O. Box 30621, Syria
9 Geography Department, Faculty of Arts and Humanities, Tishreen University, Lattakia P.O. Box 2237, Syria
* Correspondence: h.almohamad@qu.edu.sa

Abstract: Plant diversity is lower in arid regions around the world. However, semi-arid regions have very high species richness and are notable in terms of vegetation structure and plant diversity. The major goal of this study was to assess the composition and diversity of woody species with respect to edaphic properties in semi-arid lowlands of Kasur, Punjab Pakistan. Comprehensive field surveys were conducted to study the botanical diversity of woody vegetation in Kasur district (Punjab) during 2020–2022. Based on geography and vegetation richness, 120 sampling sites were selected, with each site comprising 05 transects of 500 m^2 randomly. Therefore, from each sampling site, 25 quadrats were taken for exploring the biological assortment of woody vegetation. Soil samples were collected at a depth of 9 to 12 cm and placed in a polythene bag. The soil samples were tested for soil pH, EC, OM, macronutrients (N, P, and K), and cation exchange capacity (CEC). A total of 86 woody species belonging to 61 genera and 26 families were documented from diverse habitats of semi-arid lowland of Kasur, Punjab, Pakistan. The leading family was Leguminosae having 13 genera and 21 species, followed by Moraceae, including four genera and nine species, and Bignoniaceae with seven genera and 09 species. Overall, five woody plant communities were renamed by means of the maximum indictor-valued plant species, such as those listed below; 1. EDM: *Eucalyptus-Dalbergia-Morus* community; 2. PBM: *Populus-Bombax-Morus* community; 3. ZTZ: *Ziziphus-Tamarix- Ziziphus* community; 4. PAP: *Prosopis-Acacia-Prosopis* community, and 5. BCR: *Broussonetia-Conocarpus-Ricinus* community. The CCA ordination makes it apparent that appropriate edaphic aspects, such as pH, organic matter, N, P, K, soil texture (silt, sand, and clay), and cation exchange capacity (CEC), have a significant influence on how woody species are distributed. The current effort provides a fundamental layout to realize the influences of environmental variables on the arrangement, variety, and relations of woody vegetation, which is useful to improve the conservation and management events for the ecological restoration of degraded habitation in the studied district.

Keywords: biological richness; distribution patterns; woody vegetation; geography; Punjab

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1. Introduction

Crucial information may be achieved from the biological richness of a vegetation pattern for the planning and management of protected areas, which are prerequisite for sustainable use of biodiversity, particularly due to global variations which are especially caused by anthropogenic factors [1,2]. However, in the field of ecology, identifying and understanding the mechanisms underlying these patterns remains a difficult task. In biological diversity, species richness which is an important aspect of vegetation has been formerly used widely in environmental studies [3,4]. Several theories have been tested and planned, particularly the hypothesis concerning the environment and niche conservation to understand the mechanism effecting species richness and vegetation pattern [5,6].

The vegetation, its compositional distinctions and the co-existence of species is effectively represented by the prime environment and ecological variables [7] governing the occurrence of species in any geographical landscape. Vegetation is the aggregation of plant species along with its structure, composition, distribution, and classification in relation to edaphic, climatic, and other several anthropogenic influences [8]. Vegetation is repented by the total plant species in a certain region under its environmental influences [9], with relation to the physiognomic, synthetic, analytical and quantifiable characteristics and is influenced by abiotic and biotic features. The present study was conducted with the aims to explore the ecological features, e.g., habit, life form, leaf size spectra, life cycle, and flowering phenology of wild woody flora. Studying and exploring the biological spectra (life form, leaf size) are helpful measures to comprehend eco-physiological establishment of communities which elaborates the underlying climatic conditions [10].

Woody vegetation [2], especially trees, plays a central role in the effectiveness and sustainability of ecosystems, particularly forest habitats. Because phytodiversity influences the structure, composition, and richness of allied biota, having a high degree of tree species diversity is beneficial for conserving forest ecosystems from catastrophic losses caused by illnesses and pests, as well as ensuring the enhanced functioning of ecosystem services. Although several explorations have been carried out to assess the hypotheses, researchers in the field of ecology remain unsuccessful in finding an agreement about the comparative relation of these hypotheses of species richness patterns [11,12].

Previous studies have shown that plants with varied development patterns (herbs, shrubs, and trees) have a variety of features, ecological adaption, evolutionary degrees, and evolutionary niche conservation. [13]. Furthermore, species with a diversity in size tend to have a different ability for dispersal to adapt to ecological conditions, and they may exhibit distinct responses to their environment. [14]. It can be suggested from the present findings that the results of various measures on the wide range configurations of plant types with varied range size and development patterns could be disparate for distinct life forms. The distinction in the relative impacts of several hypotheses suggested for species abundance patterns through species range in size and growth forms probably one of the most important causes for the hurdle to gain achievement in the prior investigations and it is still in pending evaluation in ecological studies [15]. Despite widespread awareness for the vitality of forest diversity, knowledge on the distribution pattern of tree diversity is still lacking. The district Kasur has a lush, wild, woody, floristic diversity due to varied topography and climate. Previously, only few preliminary research has been undertaken in this semi-arid lowlands of Punjab, Pakistan [16,17]. Therefore, widespread classification along with ordination are valuable tools to understand the local dynamics of species association along with uses, planning and conservation. As conserving trees is so critical, this study was planned to highlight the following objectives: (i) to compile the taxonomic diversity of the wild woody flora of the area; (ii) to comprehend the developing tendencies within applied taxonomic diversity to document taxa, and lastly (iii) to realize whether ecological factors impact the structure, diversity, and associations of species in this region. Due to the economic value of tree species in this region, the findings from the present study will provide sustainable management policies and habitat restoration measures particularly for the local landscape in relation to the rest of the biosphere.

2. Materials and Methods

2.1. Study Area

District Kasur is situated 150 to 240 meters above sea level and located southeast of Lahore (31°12′ N and 74°44′ E). The total area of district Kasur is 3995 km^2 and is surrounded by River Satluj in the South and Ravi in the North. It is bounded on the north by Lahore district, on the east and south-east by India, on the south-west by Okara district, and on the north-west by Nankana Sahib District Tehsils, namely Kasur, Chunian, Pattoki, and Kot Radha Kishan. Topographically, Kasur district is a semi-arid plain and basin area of Sutlej riverine District Kasur is famous for Changa Manga National Forest, Balloki Headworks, and Ganda Singh Border (Figure 1). The climate of district Kasur is moderate [16]. During summer, the climate is hot, and the temperature rises above 40 °C. The highest temperature was noted during the month of June and the lowest temperature was noted during the month of January. The highest rainfall was recorded during the month of July, more than 120 mm. The winter session extends from December to February. The temperature fluctuates between 20 and 6 °C. The average annual rainfall is 500 mm [17].

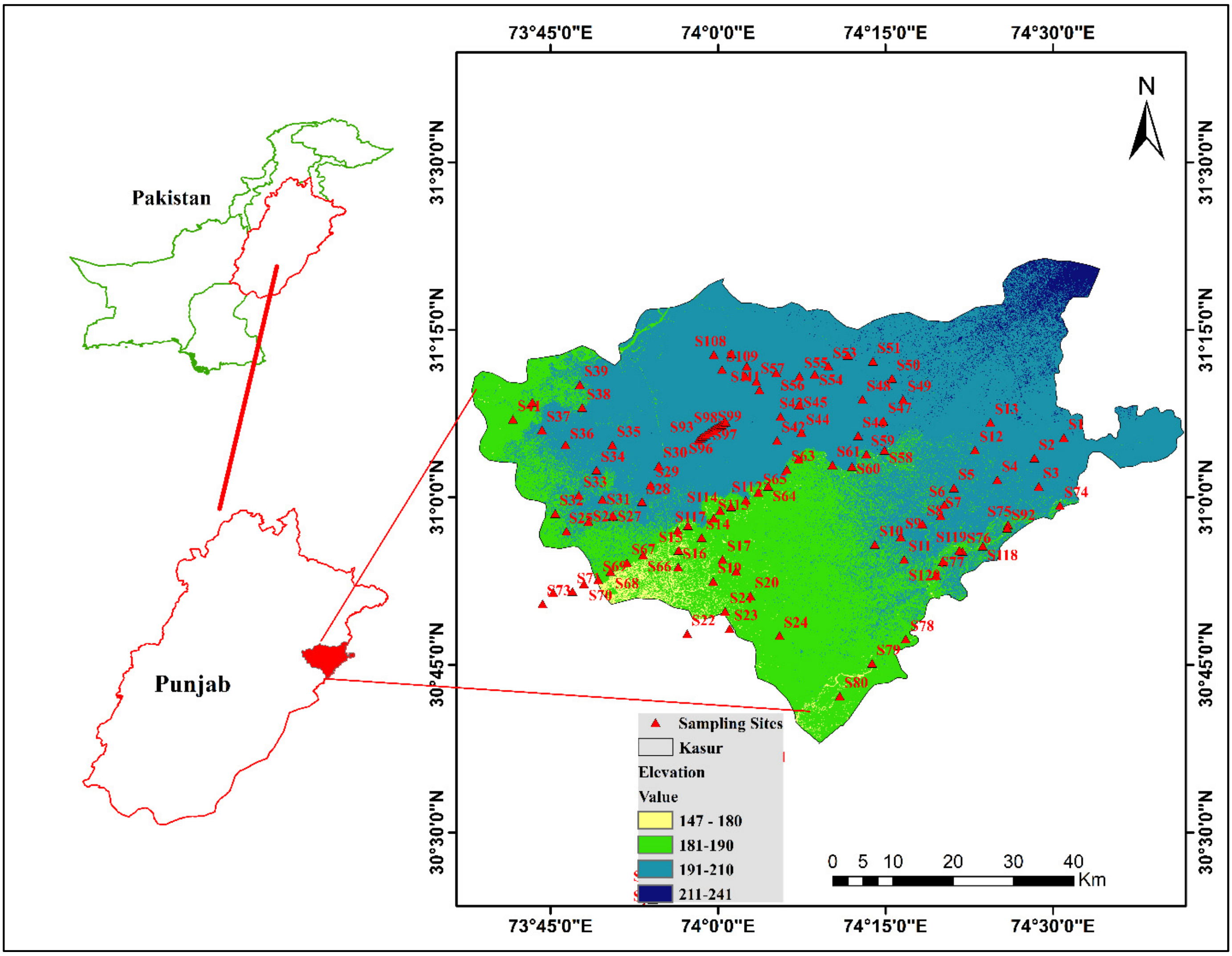

Figure 1. Study area with elevation and sampling location in the various ecosystem (riparian ecosystem, wetland ecosystem, urban ecosystem, forest ecosystem, and agro-ecosystem).

The climate data (precipitation, wind speed, humidity, and temperature) of district Kasur were acquired from the Pakistan Metrological Department (PMD) (Figure 2). Floristically, it falls in the Sahara Sindian region and hosts a significant number of plant species. The vegetation includes xerophytic and thermophilic species in the open and arid areas, but riverine belts host several macrophytes. The agricultural lands host weeds and ruderal species, e.g., *Ageratum conyzoides*, *Amaranthus Viridis*, *Coronopus didymus*, *Chenopodium album*, *Convolvulus arvensis*, *Cypreus rotundus*, *Cynodon dactylon*, *Oxalis corniculata*, *Rumex dentatus*, *Melilotus parviflora*, and *Eragrostis poaeoides* [17].

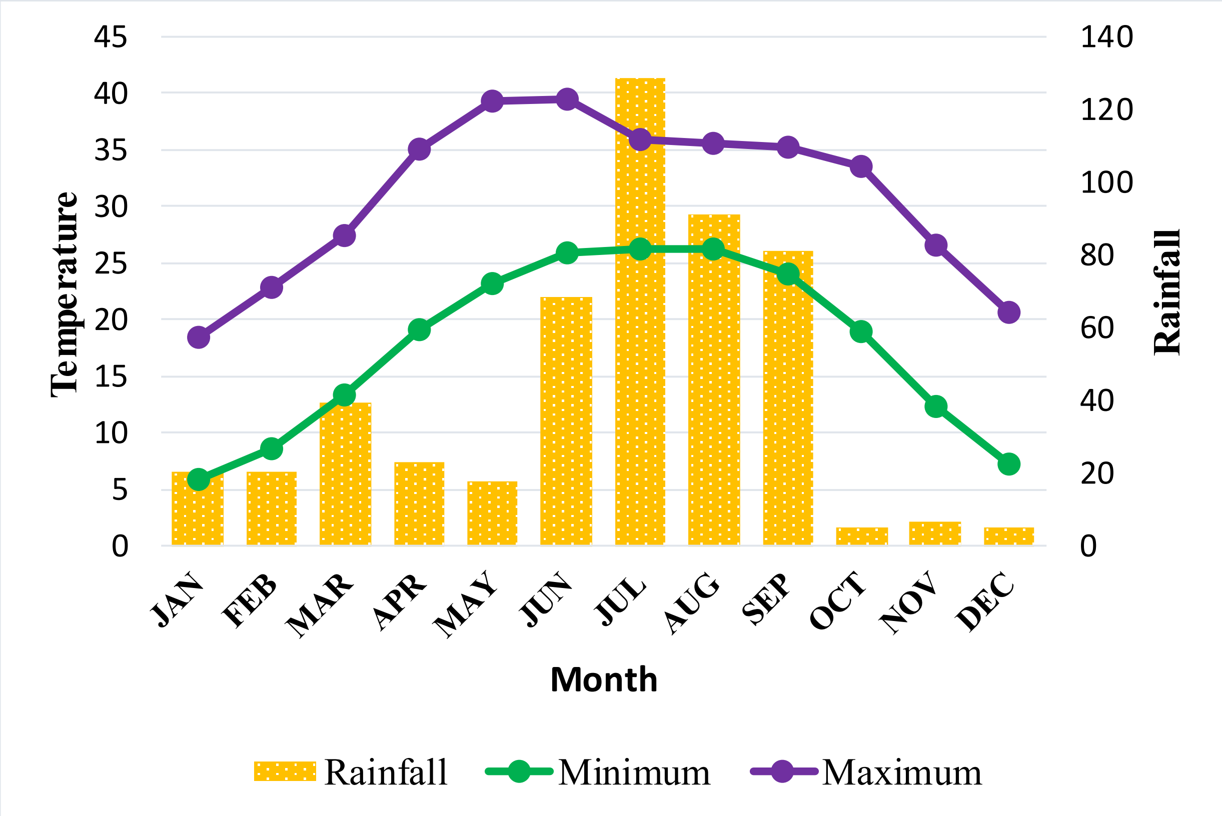

Figure 2. Climograph showing the average temperature and rainfall in district Kasur.

2.2. Field Sampling

A detailed field investigation was conducted to investigate the botanical variety of woody vegetation in Kasur district (Punjab) during 2020–2022. During field surveys, samples were collected from the forest, riparian zones, arable land, graveyard, roadside, home gardens, scrubland, sandy places, and canal bank habitats. Based on topography and vegetation richness, 120 sampling sites were selected from different habitats. At each sampling site, 5 transects of 500 m^2 in size were placed randomly. From each 500 m^2 transect, 5 quadrats of 10 m^2 were placed systematically [14]. So, from each sampling site, 25 quadrats were taken for exploring the ecological diversity of woody vegetation. Only woody vegetation was considered in the current study since it is more frequent in semi-arid lowlands. Individual woody plants diameter at breast height DBH $\geq$ 2.5 cm and height $\geq$ 2.5 m were measured from each sample plot. In the examined plots, each plant species' density, frequency, and diameter at breast height (DBH $\geq$ 2.5 cm) were recorded, and the average values for each of the sample quadrates were computed. A Garmin eTrex Global Positioning System was used to determine the geographic elements of each site, such as altitude, latitude, and longitude (GPS) [14]. Plant specimens were collected during field surveys, pressed, dried, photographed, and eventually mounted as international standard-sized herbarium sheets [18]. Following identification, all samples were cross-referenced with floristic literature using the Flora of Pakistan online (http://www.efloras.org/ accessed on 16 May 2021) [19]. To minimize confusion when identifying species, binomials and family nomenclature were employed after preliminary identification of specimens using the plant list ver. 1.1 (URL: http://www.theplantlist. org/ accessed on 16 May 2021) [18].

2.3. Soil Sampling

The position data for the plots under examination was recorded using a portable Global Positioning Equipment (GPS) system. The geographical distribution of plant groupings is influenced by the physicochemical qualities of the soil [20]. Soil sample was gathered from each sampling location with a level at a depth of 9 to 12 cm and placed in a polythene bag. The samples were thoroughly mixed, then air-dried, and rock, trash, and gravel particles greater than 2 mm in size were removed by sifting the soil samples. The soil samples were tested for soil moisture, pH, electrical conductivity, organic carbon, macronutrients (N, P, and K), and cation exchange capacity (CEC). The electrical conductivity of soil samples was measured using a conductivity meter (Wilson et al., 2012), and the soil texture (clay, sand, and silt) by hydrometer (Koehler et al., 1984), pH was measured using a pH meter [21]. The total nitrogen (N) was determined following the Kjeldahl method [22], and the soil organic carbon (SOC) was determined using the Walkley–Black method [23]. The levels of phosphorus (P) and potassium (K) were calculated [24], and CEC was measured through [25].

2.4. Indicator Species Analysis

The indicator species analysis was carried out to define indicators for each of the ecosystems in the semi-arid lowland region. This provided information regarding species' fidelity to a specific ecosystem. After determining the Indicator Values of each species using a method, a Monte Carlo Assess was performed to test for statistical significance [26]. During indicator species analysis, the relative abundance of a species in forest, riparian zones, arable land, graveyard, roadside, home gardens, scrubland, sandy places, and canal bank habitats was calculated using the following formula:

$$Relative\ abundance \left(RA_{jk}\right) = \frac{x_{kj}}{\sum_{k=1}^{g} x_{kj}} \quad (1)$$

where $RAjk$ means relative abundance,

Xkj is the abundance of species j in group k,

and g means the total number of groups.

$$Relative\ frequency \left(RF_{kj}\right) = \frac{\sum_{i=1}^{nk} b_{Ijk}}{n_k} \quad (2)$$

where $RFkj$ is the relative frequency of plant j in group k,

$bijk$ is the presence or absence of plant j in group k sample I,

and I is the sample unit.

$$Indicator\ value\ \left(IV_{Kj}\right) = 100(RA \times RF) \quad (3)$$

As a cutoff value for determining indicator species, a threshold level of 25% indication and 95% significance ($p \leq 0.05$) was employed. Furthermore, the indicator species with ($p \leq 0.05$) value were represented graphically with the help of PAST software (version 4.10).

2.5. Data Analysis

The acquired phytosociological data for plants and environmental conditions were organized and further processed in Microsoft Excel 2016 for subsequent analyses. To identify the biologically significant number of woody communities in the research area, the species abundance data was first analyzed using the Monte Carlo permutation test (ecological distance method: relative Euclidean; linkage method: Ward's) [27]. An agglomerative hierarchical clustering dendrogram was subsequently created to show how the 120 sampling sites under consideration were grouped. To establish the relative importance of each plant species in the identified woody communities (i.e., the species makeup of each community type). The hierarchical cluster analysis, chord diagram, and ternary plot were prepared using Origin Pro software. PAST software (version 4.10) [28] was used to calculate the diversity indices for each ecosystem. Finally, we calculated the Pearson correlation coefficient between the soil parameters. The data were plotted in a correlogram using the 'corrplot' package. CANOCO software (Version 4.5) [29] was applied to perform CCA [18].

3. Results

3.1. Woody Vegetation of Study Area

A total of 86 woody species belonging to 61 genera and 26 families were recorded from different habitats of semi-arid lowland of Punjab, Pakistan. The most leading families were Leguminosae with 21 species (24%), followed by Moraceae and Bignoniaceae with nine species each (10%), Apocynaceae, Combretaceae, Myrtaceae, and Salicaceae, including four species each. The remaining families have either one or two species in each (Figure 3). The number of species recorded from forest habitat was much higher than in the other habitats with 42 species (48.27%) followed by home gardens with 32 species (36.78%), arable land with 29 species (33.33%), roadside with 20 species (22.98%), riparian zones with 19 species (21.83%), canal banks with 15 species (17.24%), graveyards with 13 species (14.94%), scrubland with 12 species (13.79%), and sandy places with 10 species (11.49%) (Table 1). The distribution of woody species in different habitats is depicted in the chord diagram with different colors (Figure 4).

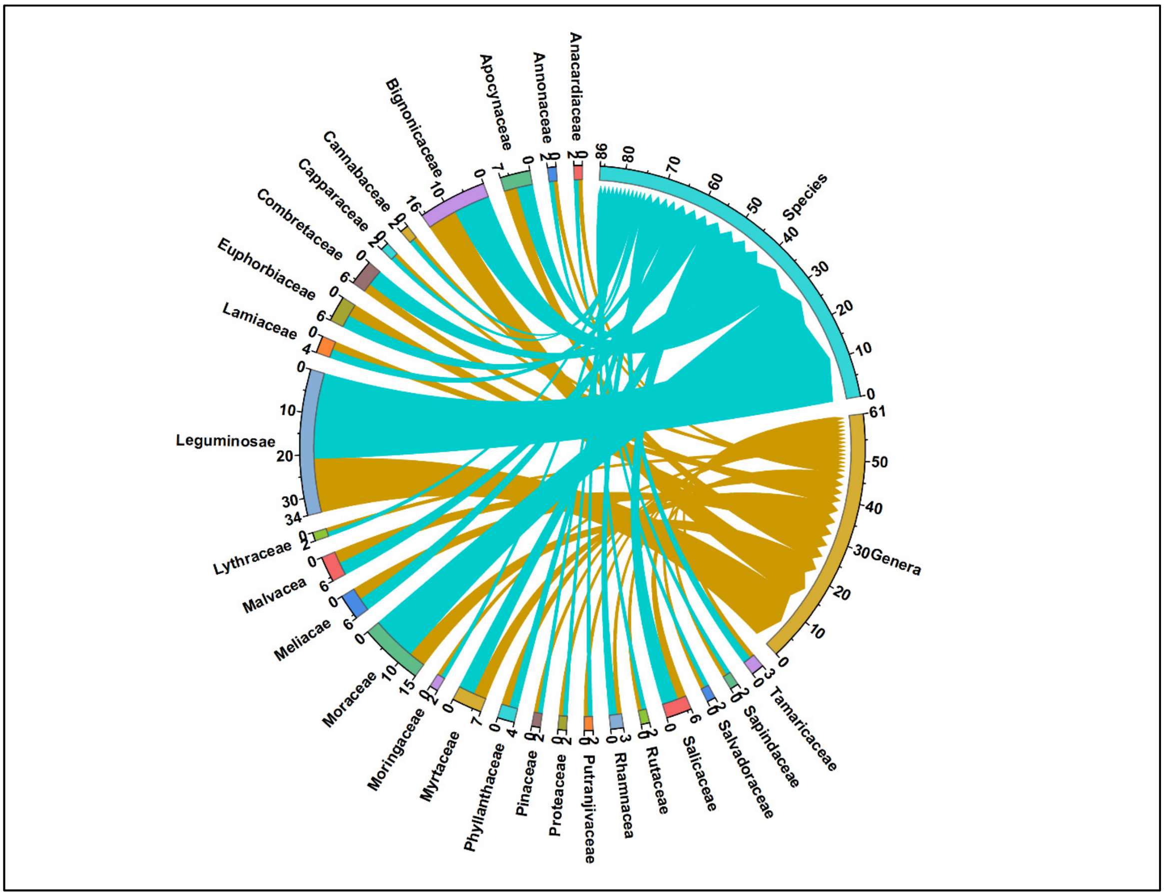

Figure 3. Chord diagram showing the number of species and genera in each family recorded from semi-arid lowland of Punjab, Pakistan.

Table 1. overall woody plants of the five communities from the study area of semi-arid lowland district Kasur Punjab, Pakistan.

Plant Name	Species Code	Community 1	Community 2	Community 3	Community 4	Community 5
Acacia farnesiana (L.) Wild	*Acac far*	10.23	9.32	13.08	69.64	35.66
Acacia modesta Wall	*Acac mod*	9	0	58.24	15.99	13.56
Acacia nilotica (L.) Delile.	*Acac nil*	31.23	62.05	51.39	78.56	35.25
Albizia lebbek (L.) Benth.	*Albi leb*	14.67	0	3.45	7.79	2.79
Albizia procera (Roxb.) Benth.	*Albi pro*	15.11	0	0	5.3	3.57
Alstonia scholaris (L.) R. Br.	*Alst sch*	32.79	0	5.67	0	16.66
Artocarpus lakucha Buch. Ham.	*Arto lak*	0	0	0	1.45	0
Azadirachta indica (L.) A. Juss	*Azad ind*	3.79	0	0	0	0
Bauhinia purpurea L.	*Bauh pur*	5.07	0	2.43	0	0
Bauhinia variegata L.	*Bauh var*	2.51	0	0	0	0
Bischofia javanica Blume	*Bisc jav*	3.1	0	0	2.12	0
Bombax ceiba L.	*Bomb cei*	23	85.13	7.54	38.8	3.45
Broussonetia papyrifera (L.) L'Herit. ex Vent.	*Brou pap*	1.23	5.78	36.07	57.1	65.01
Butea monosperma (Lain.) Taubert.	*Bute mon*	0	0	0	2.31	0
Capparis decidua (Forssk.) Edgew.	*Capp dec*	0	0	0	4.32	0
Cascabela thevetia (L.) Lippold	*Casc the*	31.02	0	0	0	10.33
Cassia fistula L.	*Cass fis*	9.68	0	2.11	0	4.32
Cassia surattensis Burn. f.	*Cass sur*	8.65	0	0	0	0
Cedrela toona Roxb.ex Wild.	*Cedr too*	0	6.4	0	3.43	0
Celtis australis L.	*Celt aus*	9.43	6.5	0	27.25	0
Chukrasia tabularis Adr. Juss.	*Chuk tab*	0	0	0	3.234	0
Conocarpus erectus L.	*Cono ere*	58.66	0	18.89	0	63.86
Cordia dichotoma G.Forst.	*Cord dic*	2.46	0	0	2.15	0
Cordia myxa L.	*Cord myx*	8.03	0	0	1.65	0
Dalbergia latifolia Roxb.	*Dalb lat*	2.98	2.33	0	2.34	0
Dalbergia sisso Roxb.	*Dalb sis*	82.66	5.88	50.88	60.45	2.34
Ehretia laevis Roxb.	*Ehr lae*	14.07	32.79	0	40.69	0
Ehretia obtusifolia Hochst. ex A.DC.	*Ehr obt*	0	0	1.23	12.11	0
Erythrina suberosa Roxb.	*Eryt sub*	0	0	5.64	0	18.91
Eucalyptus camaldulensis Dehnh.	*Euca cam*	88.22	6.64	7.48	60.31	24.05
Eucalyptus citriodora Hook.	*Euca cit*	0	0	0	2.34	15.66
Ficus benghalensis L.	*Ficu ben*	7.79	15	0	0	0
Ficus elastica Roxb. ex Hornem.	*Ficu ela*	3.66	0	0	0	0
Ficus infectoria Roxb.	*Ficu inf*	19.68	0	0	0	0
Ficus macrophylla Huegel ex Miq.	*Ficu mac*	3.21	0	0	0	0
Ficus palmata Forssk.	*Ficu pal*	1.68	8.65	30.71	39.79	0
Ficus racemosa L.	*Ficu rac*	0	8.01	0	0	0
Ficus religiosa L.	*Ficu rel*	19.77	0	2.34	0	0
Gmelina arborea Roxb. ex Sm.	*Gmel arb*	5.53	0	0	5.43	0
Grevillea robusta A. Cunn. ex R. Br.	*Grev rob*	0	6.54	2.34	0	4.3
Grewia tenax (Forssk.) Fiori	*Grew ten*	0	0	11.17	9.07	0
Heterophragma adenophylla (Wall. ex G. Don) Dop	*Hete ade*	7.77	0	0	0	0
Jacaranda ovalifolia R. Br	*Jaca ova*	4.32	0	0	0	0
Kigelia africana (Lam.) Benth.	*Kige afr*	4.32	0	0	0	0
Lagerstroemia indica L.	*Lage ind*	31.05	0	0	0	3.41
Leucaena leucocephala (Lam.) de Wit	*Leuc leu*	0	8.54	0	52.13	0
Mangifera indica L.	*Mang ind*	4.69	0	7.78	0	0
Moringa oleifera Lam.	*Mori ole*	5.11	10.32	0	0	0
Morus alba L.	*Moru alb*	27.77	77.43	3.35	47.99	0
Morus nigra L.	*Moru nig*	71.57	2.3	3.23	54.96	0
Morus serrata Roxb.	*Moru ser*	6.43	0	0	2.11	0
Oroxylum indicum (L.) Kurz	*Orox ind*	3.21	0	3.1	0	0
Parkinsonia aculeata L.	*Park acu*	0	0	31.91	0	31.69
Phyllanthus emblica L.	*Phyl emb*	3.21	0	0	0	0
Pinus roxburghii Sargent	*Pinu rox*	7.55	0	0	0	0
Plumeria obtusa L.	*Plum obt*	3.74	0	0	0	0
Plumeria rubra L.	*Plum rub*	2.12	0	0	0	0
Polyalthia longifolia Benth, & Hook. f.	*Poly lon*	40.39	0	0	0	0
Poncirus trifoliate (L.) Raf	*Ponci tri*	1.32	0	0	0	0
Pongamia pinnata (L.) Merrill.	*Pong pin*	13.87	27.64	12.21	11.55	23.32
Populus alba L.	*Popu alb*	31.98	50.88	0	18.18	0
Populus nigra L.	*Popu nig*	29.11	95.28	22.56	15.19	0
Prosopis cineraria (L.) Druce	*Pros cin*	0	0	5.61	72.21	45.57
Prosopis glandulosa Torr.	*Pros gla*	0	3.23	17.68	2.54	2.23

Table 1. *Cont.*

Plant Name	Species Code	Community 1	Community 2	Community 3	Community 4	Community 5
Prosopis juliflora (Sw.) DC.	*Pros jul*	0	30.79	40.89	85.32	45.78
Psidium guajava L.	*Psid gua*	47.65	24.77	0	0	0
Pterospermum acerifolium (L.) Willd	*Pter ace*	3.96	0	0	0	0
Putranjiva roxburghii (Wall.) Hurusawa	*Putr rox*	2.34	0	0	0	0
Ricinus communis L.	*Rici com*	6.9	7.65	9.43	21.02	54.66
Salix alba L.	*Sali alb*	0	3.45	0	15.2	0
Salix tetrasperma Roxb.	*Sali tet*	0	3.25	0	7.54	0
Salvadora oleoides Decne.	*Salv ole*	27.92	0	0	0	7.77
Sapindus mukorossi Gaertn	*Sapi muk*	4.22	0	0	0	0
Sapium sebiferum (L.) Roxb.	*Sapi seb*	0	32.9	0	30.24	0
Saraca asoca (Roxb.) De Wilde.	*Sara aso*	3.23	0	0	0	0
Syzygium cumini (L.) Skeels	*Syzy cum*	14.76	0	3.56	0	0
Tamarix aphylla (Linn.) Karst.	*Tama aph*	0	0	64.68	35.8	0
Tamarix dioica Roxb. ex Roth	*Tama dio*	0	0	32.34	0	0
Tecoma stans L.	*Teco sta*	66.87	0	0	0	0
Tectona grandis L. f.	*Tect gra*	2.54	0	0	0	0
Terminalia belerica Roxb.	*Term bel*	2.34	0	0	0	0
Terminalia chebula Retz.	*Term che*	2.11	0	0	0	0
Terminalia. arjuna (Roxb. Ex DC) Wt. & Arn.	*Term arj*	39.64	6.36	34.2	16.29	0
Trewia nudiflora L.	*Trew nud*	1.23	0	0	5.62	0
Ziziphus jujuba Mill.	*Zizi juj*	20.33	21.45	92.63	19.4	2.12
Ziziphus nummularia (Burm.f.) Wight & Arn.	*Zizi num*	15.83	21.43	61.83	45.3	3.23

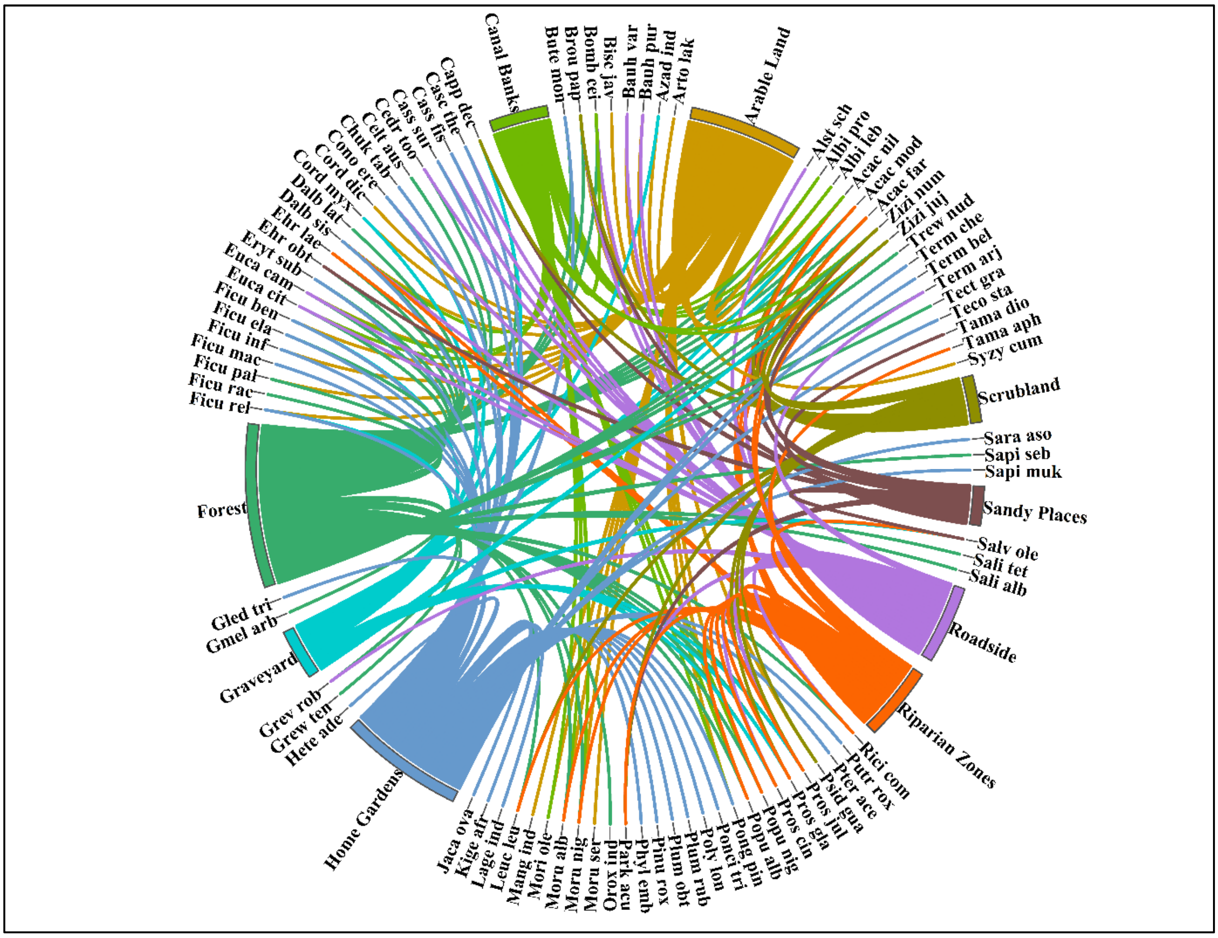

Figure 4. Chord diagram showing the woody species distribution in different habitat types of semi-arid lowland of Punjab, Pakistan.

3.2. Classification of Woody Vegetation

Using Ward's agglomerative clustering method, the 86 woody species recorded from 120 sampling sites from semi-arid lowland were classified into 5 major community types (Table 1). The five woody plant communities were renamed using the highest indictor-valued plant species, such as those listed below; 1. EDM: *Eucalyptus-Dalbergia-Morus* community; 2. PBM: *Populus-Bombax-Morus* community; 3. ZTZ: *Ziziphus-Tamarix- Ziziphus* community; 4. PAP: *Prosopis-Acacia-Prosopis* community, and 5. BCR: *Broussonetia-Conocarpus-Ricinus* community.

The grouping pattern and sample size of each plant community is shown in an agglomerative hierarchical clustering tree of the 120 examined woody vegetation samples (Figure 5). The dendrogram tree shows that the closely related vegetation samples (those with the least difference in species composition) clustered together and were represented by the same color coding. Overall, this graph shows that the district Kasur possessed five woody plant communities comprised of different plant species. The results of this study also indicate that the majority of the examined sampling sites (53) belong to community 1, whereas community 3 contains the lowest number of sampling sites (11).

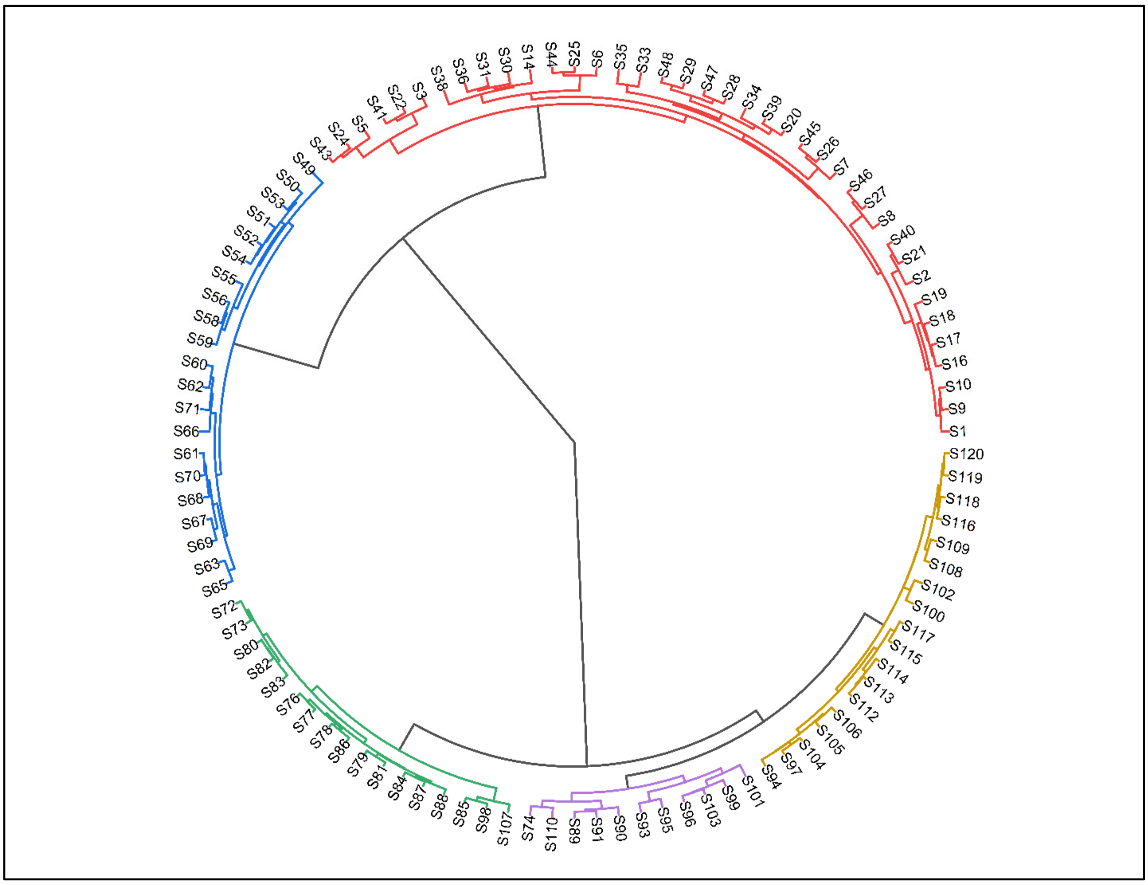

Figure 5. An agglomerative hierarchical clustering dendrogram of the 120 sampling sites, illustrating the five woody plant communities in the semi-arid lowland Punjab, Pakistan.

Color Coding: Red = 1. EDM: *Eucalyptus-Dalbergia-Morus* community;
Yellow = 2.PBM: *Populus-Bombax-Morus* community;
Purple = 3. ZTZ: *Ziziphus-Tamarix- Ziziphus* community;
Green = 4. PAP: *Prosopis-Acacia-Prosopis* community;
Blue = 5. BCR: *Broussonetia-Conocarpus-Ricinus* community.

3.3. Community 01 (EDM: Eucalyptus-Dalbergia-Morus Community)

This plant community was found in forest, arable land, canal banks, home gardens, and roadside plantations sampling sites. The community comprised of 53 sampling sites and 66 (76.7%) woody species from the study area. The indicator species in this community have significant *p*-value include *Eucalyptus camaldulensis, Dalbergia sisso,* and *Morus nigra.* The other leading species in this community include *Terminalia arjuna, Tecoma stans, Psidium guajava, Populus alba, Polyalthia longifolia, Albizia lebbek, Alstonia scholaris, Cascabela thevetia,* and *Conocarpus erectus.* Higher Shannon's diversity (3.7 ± 0.36), Simpson diversity (0.96 ± 0.29), Margalef's richness (9.19 ± 1.32), and Pielou's evenness (0.88 ± 0.03) were recorded in this community.

3.4. Community 02 (PBM: Populus-Bombax-Morus Community)

This plant community was also recorded from arable land, plantations, canal banks, and roadside sampling sites. The community comprised of 18 sampling sites and 31 (36%) woody species from the semi-arid lowland district Kasur Punjab, Pakistan. The indicator species in this community with significant *p*-value include *Populus nigra, Bombax ceiba,* and *Morus alba.* The other leading species in this community include *Acacia nilotica, Broussonetia papyrifera, Dalbergia sisso, Ehretia laevis, Populus alba, Prosopis juliflora, Terminalia. arjuna, Sapium sebiferum, Prosopis juliflora, Pongamia pinnata,* and *Acacia farnesiana.* Higher Shannon's diversity (3.04 ± 0.33), Simpson diversity (0.94 ± 0.23), Margalef's richness (4.43 ± 1.13), and Pielou's evenness (0.77 ± 0.02) were recorded in this community.

3.5. Community 03 (ZTZ: Ziziphus-Tamarix- Ziziphus Community)

This woody community was recorded from riparian zones and sandy places sampling sites. The community comprised of 11 sampling sites and 34 (40.69%) woody species from the semi-arid lowland district Kasur Punjab, Pakistan. The indicator species in this community with significant *p*-value include *Ziziphus jujuba, Tamarix aphylla,* and *Ziziphus nummularia.* The other leading species in this community include *Tamarix dioica, Prosopis juliflora, Parkinsonia aculeata, Ficus palmata, Dalbergia sisso, Broussonetia papyrifera, Acacia modesta, Acacia nilotica, Grewia tenax, Prosopis glandulosa,* and *Prosopis cineraria.* Higher Shannon's diversity (3.08 ± 0.24), Simpson diversity (0.94 ± 0.24), Margalef's richness (5.14 ± 1.21), and Pielou's evenness (0.84 ± 0.03) were recorded in this community.

3.6. Community 04 (PAP: Prosopis-Acacia-Prosopis Community)

The sampling sites of this community mainly comprised of scrubland, dry places, and along the roadsides. The community comprised of 17 sampling sites and 44 (51.16%) woody species from the semi-arid lowland district Kasur Punjab, Pakistan. The indicator species in this community with significant *p*-value include *Prosopis juliflora, Acacia nilotica,* and *Prosopis cineraria.* The other notable species in this community include *Acacia farnesiana, Broussonetia papyrifera, Celtis australis, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Leucaena leucocephala, Sapium sebiferum, Tamarix aphylla, Ziziphus nummularia,* and *Ricinus communis.* Higher Shannon's diversity (3.36 ± 0.15), Simpson diversity (0.95 ± 0.31), Margalef's richness (6.09 ± 1.31), and Pielou's evenness (0.886 ± 0.02) were recorded in this community.

3.7. Community 05 (BCR: Broussonetia-Conocarpus-Ricinus Community)

The sampling sites of this community mainly comprised of scrubland, home gardens, arable land, and along the roadsides. The community comprised of 21 sampling sites and 26 (30.23%) woody species from the semi-arid lowland district Kasur Punjab, Pakistan. The indicator species in this community with significant *p*-value include *Broussonetia papyrifera, Conocarpus erectus,* and *Ricinus communis.* The other notable species in this community include *Alstonia scholaris, Erythrina suberosa, Eucalyptus camaldulensis, Parkinsonia aculeata, Salvadora oleoides, Prosopis juliflora, Pongamia pinnata, Acacia farnesiana, Cascabela thevetia,* and *Acacia modesta.* Higher Shannon's diversity (2.83 ± 0.13), Simpson diversity (0.92 ± 0.18), Margalef's richness (3.98 ± 1.12), and Pielou's evenness (0.72 ± 0.01) were recorded in this community.

3.8. Community 05 (BCR: Broussonetia-Conocarpus-Ricinus Community)

The importance value of all recorded woody species is depicted in Figure 6. The species *Acacia nilotica, Dalbergia sisso, Broussonetia papyrifera, Bombax ceiba, Eucalyptus camaldulensis*, and *Ziziphus nummularia* were the most frequent species in semi-arid lowland recorded from all five community types with different IV values (Figure 6).

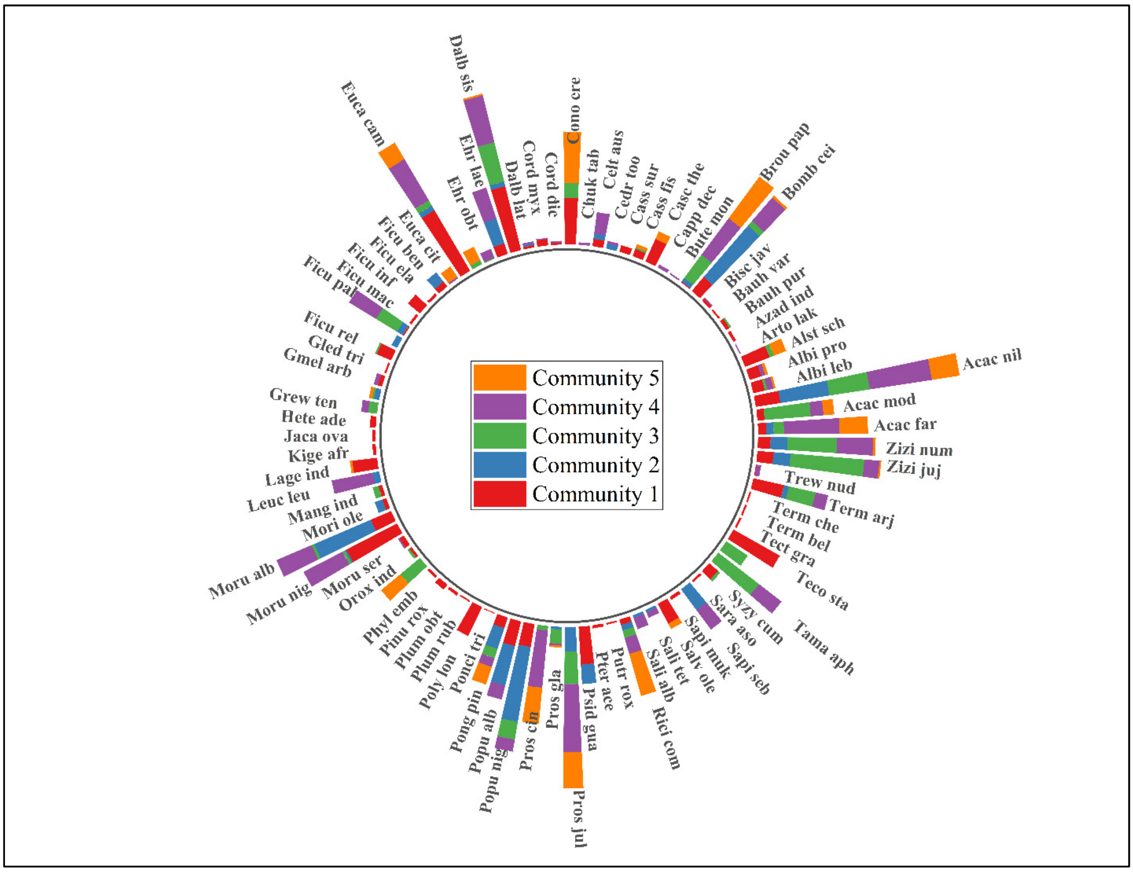

Figure 6. Radial stack bar plot showing the IV of woody species in different communities recorded from semi-arid lowland Kasur Punjab, Pakistan.

3.9. Role of Soil Properties on Distribution of Woody Vegetation

The CCA ordination makes it evident that applicable edaphic factors, such as pH, moisture, organic matter, N, P, K, soil texture (silt, sand, and clay), and cation exchange capacity (CEC), have a significant impact on how woody species are distributed. Each triangle represented a distinct species of woody vegetation, with the distance between them showing how similar they are to one another. The species in the first quadrat were under the influence of silt, potassium (K), and electrical conductance (EC), while the species in second quadrat were influenced by soil organic carbon (SOC), cation exchange capacity (CEC), and nitrogen (N). The distribution of woody species in third quadrat was impacted by sand, clay, and moisture. The distribution of woody species found in fourth quadrat of CCA diagram was controlled by soil pH and phosphorus concentration in soil (Figure 7). The first axis identified 6.3 variations, the second, 9.7, and the third and fourth, 12.4–14.8 of the total variation, indicating that soil pH, soil moisture, sand, clay, and phosphorus have a strong relationship with the third and fourth axes and have a significant impact on the diversity patterns of wild grass species (Table 2).

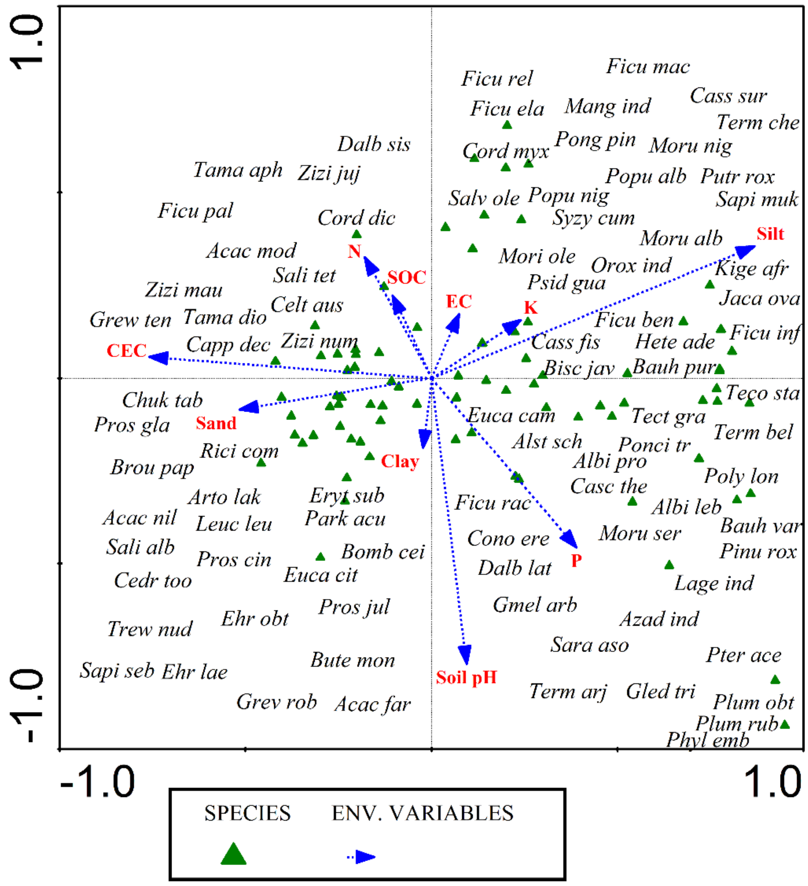

Figure 7. CCA analysis of woody vegetation in semi-arid lowland district Kasur Punjab, Pakistan.

Table 2. Summary of CCA analysis of woody vegetation in semi-arid lowland of Punjab, Pakistan.

Axes	1	2	3	4
Eigen values	0.437	0.24	0.18	0.167
Species-environment associations	0.907	0.768	0.821	0.755
Accumulative percentage variance of wild grass species data	6.3	9.8	12.4	14.8
Accumulative percentage variance of species-environment relation	26.1	40.4	51.2	61.2
Total inertia	6.912			
Sum of all eigen values	6.912			
Sum of all canonical eigenvalues	1.675			
Monte-Carlo test				
Test of significance of first canonical axis: eigenvalue	0.437			
F-ratio	3.240			
***p*-value**	0.0020			
Test of significance of total canonical axes; Trace	1.675			
F-ratio	1.396			
***p*-value**	0.0020			

The woody species that are sensitive to pH and phosphorus (P) include *Albizia procera, Alstonia scholaris, Bischofia javanica, Cascabela thevetia, Albizia lebbek, Gleditsia triacanthos, Plumeria obtusa, Plumeria rubra, Phyllanthus emblica, Lagerstroemia indica, Gmelina arborea, Conocarpus erectus, Tecoma stans, Saraca asoca, Tectona grandis*, and *Polyalthia longifolia*. Soil moisture and soil texture (sand and clay) also have an impact of distribution of grasses. However, the woody species that are positively associated with their values comprise *Acacia farnesiana, Bombax ceiba, Prosopis cineraria, Butea monosperma, Erythrina suberosa, Ehretia laevis, Acacia nilotica, Prosopis cineraria, Sapium sebiferum, Cedrela toona, Eucalyptus citriodora, Leucaena leucocephala, Parkinsonia aculeate, Broussonetia papyrifera, Grevillea robusta, Prosopis glandulosa, Chukrasia tabularis, Ehretia obtusifolia, Trewia nudiflora*, and *Salix alba*. The species impacted by nitrogen (N), soil organic carbon (SOC), and cation exchange capacity (CEC) include *Dalbergia sisso, Ziziphus jujuba, Ziziphus nummularia, Acacia modesta, Celtis australis, Salix tetrasperma, Tamarix aphylla, Tamarix dioica, Cordia dichotoma, Capparis decidua*, and *Grewia tenax*. The species that were sensitive to electrical conductance (EC), potassium (K), and silt include *Bauhinia purpurea, Heterophragma, Ficus elastica, Ficus infectoria, Ficus religiosaMangifera indica, Putranjiva roxburghii, Cordia myxa, Ficus macrophylla, Salvadora oleoides, Syzygium cumini, Kigelia africana, Cassia surattensis, Morus alba, Morus nigra, Cassia fistula, Pongamia pinnata*, and *Terminalia chebula* (Figure 7).

Silt, sand, and clay were significantly associated with woody community distribution and the relationship between EDM, PBM, ZTZ, PAP, and BCR woody communities was shown in a ternary with the aforementioned three edaphic factors (Figure 8). According to the soil composition based on these three variables, it was also possible to clearly see a clustering in the woody communities. EDM-community was hosted by soil having sandy texture and PAP-community hosted by soil having silty texture. The other three communities (PBM, BCR, and ZTZ) were hosted by soil having equal percentages of silt, sand, and clay (Figure 8).

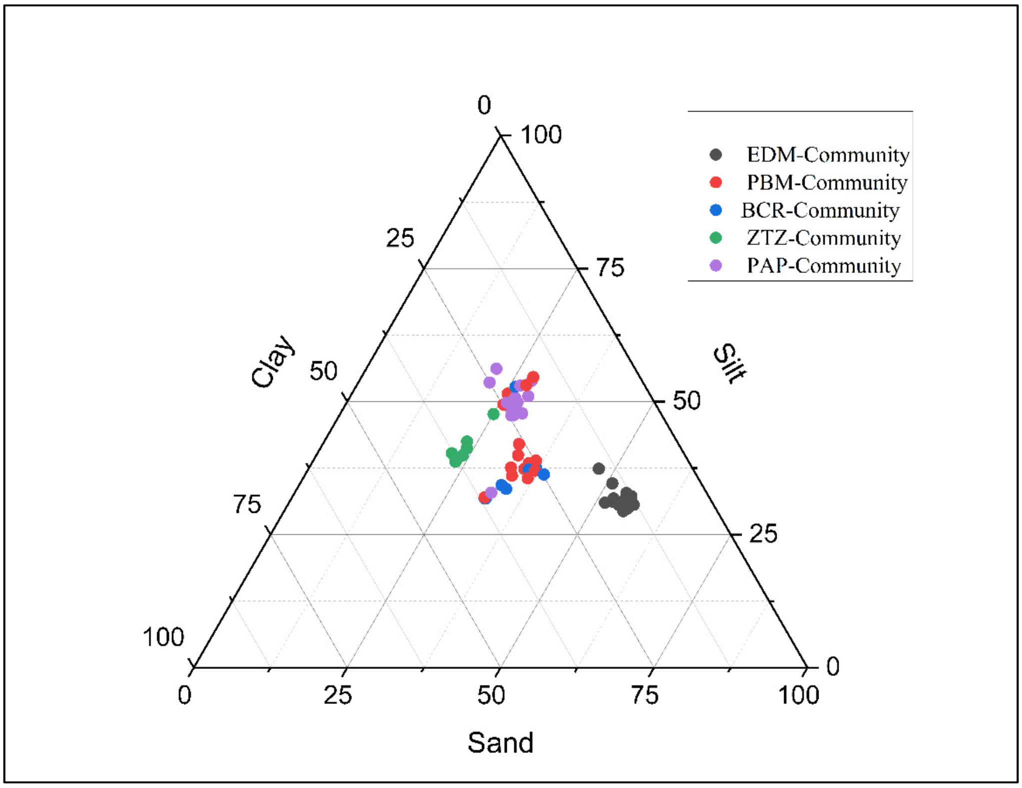

Figure 8. Ternary plot showing the distribution of five woody vegetation communities in semi-arid lowlands of Kasur, Punjab Pakistan. Ternary plot based on soil texture (silt, clay, and sand). (See Figure 5 description for full name of woody communities).

3.10. Correlation of Soil Factors

The interrelationship between several soil factors was calculated using Pearson correlation. Silt is positively correlated with potassium (K), soil organic carbon (SOC) and clay are positively correlated with nitrogen (N), and clay is also positively correlated with the cation exchange capacity (CEC) of soil. Sand and silts are negatively correlated with cation exchange capacity (CEC) (Figure 9).

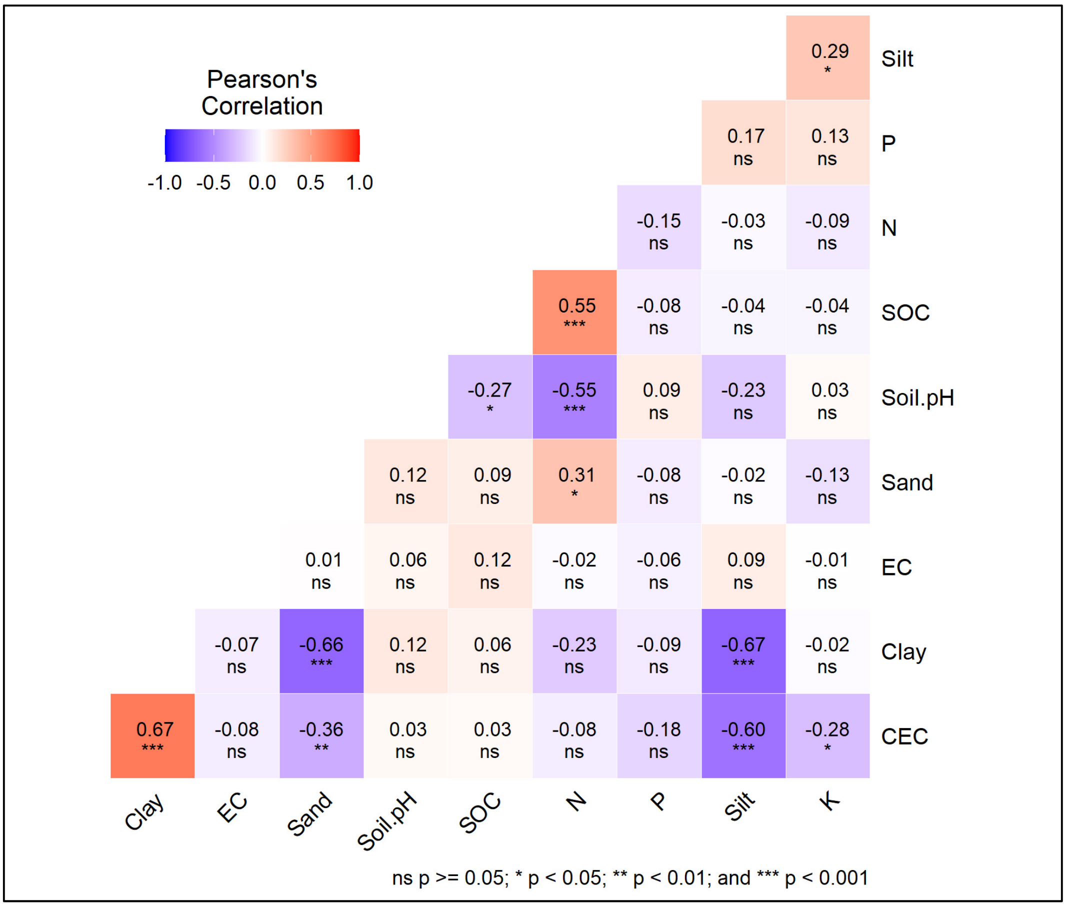

Figure 9. Pearson correlation between soil variables in semi-arid lowland district Kasur, Punjab Pakistan.

4. Discussion

Our findings emphasize the significance of the semi-arid lowlands of Punjab, Pakistan for the conservation of native flora in diverse landscapes. Our findings are critical for the development and application of management techniques in rural environments to enhance biodiversity protection without halting livestock production. The field survey results showed that study region has a high species diversity. The current study identified 86 woody species belonging to 61 genera and 26 families from diverse habitats of semi-arid lowland of Kasur, Punjab, Pakistan. The most leading families were Leguminosae with 21 species. Healso reported Leguminosae as dominant family in Margalla Foothills Pakistan [30]. The other leading families were Moraceae and Bignoniaceae which are well-known in the tropics for their diversity, variety, and abundance [16]. Home gardens host a higher number of species as compared to scrublands, canal banks, roadside, graveyard, arable land, and riparian zones. Several woody species that were either rare or non-existent in the other habitats were found in the home gardens. Tolera et al. also reported higher diversity of woody species from south-central highlands of Ethopia [31]. Some of these species included exotic trees, e.g., *Eucalyptus* spp. and *Broussonetia papyrifera*, and fruit trees, e.g., *Syzygium cumini* and *Mangifera indica*, all of which are economically or nutritionally important to farmers. The majority of the species found in the home gardens, on the other hand, were indigenous tree species brought from either other areas or other countries.

Various types of analysis have been utilized in the current ecological inquiry to quantify the recorded data of all species and stands in relation to geographic and environmental gradients. Plant community structure and distribution patterns in Himalayan forests are poorly understood. The results presented in this study clearly explain the distribution pattern of woody species composition in these microhabitats using the quantitative classification method (Ward's method) and the ordination approach (CCA). Five woody plant communities were found in the semi-arid lowlands of Pakistan based on the results of the hierarchical cluster analysis. The three community types (EDM, PBM, and BCR) were distributed in forest, roadside, arable land, home garden, and canal banks microhabitat. The floristic composition of the recognized five woody communities distinguishes them. This could be due to changes in environmental conditions. According to [14,32,33], the variation in species composition within plant communities is most likely caused by environmental conditions. Nonetheless, species diversity and richness varied between plant habitats. For example, the EDM-community has the highest species richness and diversity. The BCR-community, on the other hand, has the lowest species richness and diversity among the other community types. The great species variety and richness of EDM-community may be attributed to the community's largest microhabitat ranges. Furthermore, the BCR-community is the most troubled community due to settlement, agricultural growth, animal overgrazing, and land degradation.

In different aspects, as mentioned in this study, consistent to our hypothesis, shrubby vegetation had higher specialization than tree vegetation [34]. In other words, shrubs had high precise preferences as that of trees in various aspects. Broadly tree species distribution was chiefly affected by climatic conditions like temperature and rainfall. As shrubs are shallow feeders as that of tress, so are vulnerable to native ecological factors such as soil and precipitation. In spite of topography and soil features (physical and chemical), canopy cover also affects shrubs. Hence, shrubs largely displayed more specific distribution preferences than trees in different aspects of the forest ecosystem [35,36].

Understanding the communities of woody species in a particular environment depends on the interaction between plant communities, soil characteristics, and topography [20,37]. Our findings indicate that the distribution of woody plant species within the identified communities is significantly influenced by the spatial diversity in soil properties and topography across the semi-arid lowlands Punjab Pakistan. The main indicator species were *Dalbergia sisso, Eucalyptus camaldulensis, Populus alba, Prosopis cineraria, Prosopis juliflora, Ricinus communis, Tamarix dioica*, and *Ziziphus nummularia*. A similar pattern of woody species was recorded from another arid region of Pakistan [14,20,27,38]. In the studied region, the distribution of woody communities reflects the impact of soil characteristics. Although certain community types overlap, soil texture was shown to be the main environmental variable that explained variations in plant species distribution and patterns of plant community development. Other researchers in Pakistan have also found that soil texture is the most important soil variable in determining vegetation composition [26,27,39]. Furthermore, potassium (K) is significant in identifying the ecological groupings and species richness in the current study since it regulates photosynthesis, carbohydrate transport, protein synthesis, and other physiological functions [40]. The indicator species positively associated with potassium (K) include *M. alba*, *M. nigra*, and *P. alba*. Ahmad et al. also reported *P. alba* and *M. alba* as indicator species in marble polluted ecosystem of Pakistan [41].

In the arid tropical regions, ecological studies, in particular vegetation analysis, are crucial to understanding the actual picture of species compositional variations and their underlying environmental drivers throughout both time and geographic scales [42,43]. Documenting changes in species abundance over various environmental gradients can aid in determining the value of the various predictors [27,44]. In many biological processes, nitrogen is a crucial nutrient, and it is also the primary driver of plant development. It also has a significant impact on the fauna and flora of the soil, which can either increase the availability of nutrients to plants or bind them in biological processes and growth, leading to temporary deficits in plants. The leaching of nitrogen occurs as well, especially in well-drained soils [45,46]. The key soil components that have an impact on the distribution of the ZTZ-community were nitrogen and soil organic carbon (SOC). The indicator species positively associated with nitrogen and soil organic carbon include *Z. jujube*, *Z. nummularia*, *D. sisso*, and *T. aphylla*.

Anthropogenic impacts [47,48] upon the spreading of the invading species in distinct surroundings can be described by the physical shape of the landscape. For example, those landscapes that are moderate in advance nations have been revealed to have better plant diversity due to a more heterogeneous landscape [49,50]. There are several zones that have scarce habitat niches for supporting the diversity and abundance to other regions. Our findings are consistent with these observations with richness of targeted species and overall abundance significantly less in the urban sector. The physical features of the landscape elucidate part of the observed patterns. Other potentially key factors are dispersal mechanism, introduction histories, and current along with past human uses and preferences. The rest of this section discusses plausible descriptions for the spatial pattern of occurrence and abundance of the species found in this study.

5. Conclusions

This study found that the district of Kasur in semi-arid lowland Pakistan supports a total of five woody vegetative communities that are notably different from one another. This exhaustive first-ever survey reports 86 woody plants, illustrating a highly diversified, semi-arid tropical region. The five woody plant communities were identified using the indicator species analysis, such as; 1. EDM: *Eucalyptus-Dalbergia-Morus* community; 2. PBM: *Populus-Bombax-Morus* community; 3. ZTZ: *Ziziphus-Tamarix- Ziziphus* community; 4. PAP: *Prosopis-Acacia-Prosopis* community, and 5. BCR: *Broussonetia-Conocarpus-Ricinus* community. Numerous environmental factors play a key role in regulating the species distribution in the studied area. The most important factors are the soil pH, soil moisture, sand, clay, and phosphorus. The mapping of species diversity was performed, and the data can be utilized to identify conservation hotspots. Overall, this study found that a range of variables are impairing the ecosystem's ability to function normally in this Pakistani part of the semi-arid tropics. Based on the findings of this study, soil and vegetation assessment analysis may be helpful in determining the most appropriate habitat manipulation techniques, such as planting, top-soiling, and irrigation techniques for the rehabilitation of degraded lands in the semi-arid region. To preserve this priceless local biodiversity and avert the potential extinction of the rare plant species, sustainable resource management and the implementation of conservation programs are necessary.

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