Taiwania 71(2): 284–296, **2026**
DOI: 10.6165/tai.2026.71.284

Indigenous plant knowledge and ethnobotanical patterns in District Kasur and surrounding regions of Punjab, Pakistan

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(Manuscript received 19 January 2026; Accepted 24 March 2026; Online published 31 March 2026)

ABSTRACT: Indigenous plant knowledge is central to biodiversity use and livelihood support in subtropical lowland agroecosystems, yet its association with land-use–defined settlement types remains insufficiently documented. This study aimed to document and compare ethnobotanical diversity and plant-use patterns across five settlement types in Punjab, Pakistan. Ethnobotanical data were collected from 2022 to 2024 through open-ended interviews with 300 respondents representing forest, riverine, farmland, rural, and urban settlements. Field walks, specimen collection, and taxonomic identification were conducted using the Flora of Pakistan and Plants of the World Online. Species overlaps were examined using Venn diagrams, and Principal Component Analysis (PCA) was applied to assess settlement-wise knowledge patterns. A total of 373 plant species belonging to 69 families were recorded across the study area. Medicinal plants constituted the dominant use category (297 species), followed by fodder, ornamental, timber, vegetable, and fruit plants. Forest settlements showed the highest species richness (215 species), while urban areas recorded the lowest (89 species), although several taxa were unique to urban habitats. Six culturally important species were consistently reported across all settlement types, indicating broad ecological tolerance. High species overlap occurred between forest and riverine as well as forest and farmland settlements. Farmland communities documented numerous cultivated and semi-wild taxa, whereas rural settlements integrated both wild and managed resources. Urban respondents preferentially maintained ornamentals and fruit trees associated with cultural value and managed landscapes. The spatial distribution of shared and exclusive taxa reflects localized ecological knowledge structured by land-use heterogeneity in subtropical lowlands.

KEY WORDS: Agroecosystems, biodiversity, ethnobotany, indigenous knowledge, subtropical region.

INTRODUCTION

Indigenous plant knowledge represents accumulated ecological understanding, cultural practice, and resource management developed through long interaction with local ecosystems (Varghese and Crawford, 2021). It goes beyond practical plant use, embracing spiritual, medicinal, nutritional, and ecological dimensions that together form a rich web of cultural and biological heritage (Turner *et al.*, 2022). This kind of knowledge equips communities with the ability to respond to changing circumstances, ensure food and health security as well as ecosystem resilience (Kala, 2022). In many cases, Indigenous communities have developed remarkably refined systems for classifying plants, recognizing subtle differences in form, seasonal behavior, and habitat that often go unnoticed in formal scientific taxonomy (Ellen, 2023). There is growing recognition among scholars that indigenous ethnobotanical knowledge is dynamic with socio-economic and demographic change as well as environmental shifts continually modifying it (Mohd Salim *et al.*, 2023). It is thus important to document this knowledge not only to conserve the culture but also inform the current methods of sustainable resource management, biodiversity conservation and climate change adaptation (McLean *et al.*, 2023; Rasheed *et al.*, 2024). The indigenous plant knowledge will act as an intermediary between cultural identity and ecological stewardship, and can provide knowledge that has not been fully applied in mainstream science and policy (Sinthumule, 2023).

The patterns of land use have a significant effect on diversity and distribution of plants that communities can use, and hence affect the interaction and utilization of botanical resources by people (Hong and Zimmerer, 2022; Akram and Alam, 2025). The land types offer a distinct collection of species and adequate difference in knowledge, intensity of use, and cultural value (Jin *et al.*, 2022; Shang *et al.*, 2024). The effect of climate change, the increasing speed of which now complicates these patterns, upsets the ecological balance, changes distribution, and destabilizes systems of managing resources traditionally (Ralte *et al.*, 2024). To the indigenous and local communities, these changes may decrease the availability of important medicinal and food plants, fodder, and cultural plants and open up possibilities of new adaptations and innovations (Imoro *et al.*, 2021; Zhao *et al.*, 2023). It is therefore important to understand the interrelationships between land use, ethnobotanical knowledge and climate variability (Rivera-Ferre *et al.*, 2021). It reveals both the fragility of human–plant relationships under environmental stress and the resilience of communities that adapt to preserve their cultural landscapes (Wang *et al.*, 2018; Haq *et al.*, 2024). Capturing these dynamics can provide a foundation for developing more sustainable approaches to land management and conservation (Dieng *et al.*, 2023).

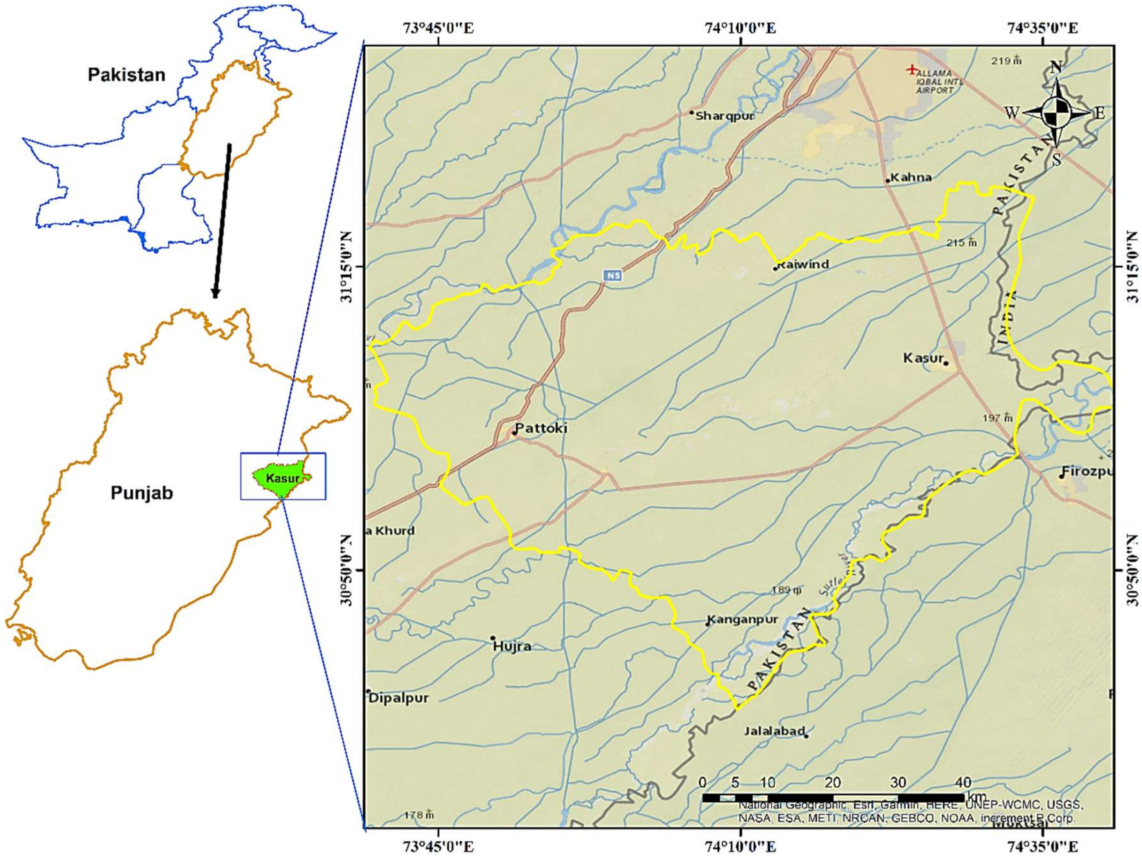

Fig. 1. Study area map showing the location of District Kasur in Punjab and Pakistan.

Subtropical lowlands comprise mosaics of forests, agricultural lands, river valleys, rural settlements, and expanding urban areas that support diverse plant resources central to local livelihoods (Maroyi 2022; Zhao and Deng 2024). Despite their ecological and socio-economic importance, the distribution of plant use across different land-use contexts in these landscapes remains poorly documented (Davison *et al*., 2021), and few studies explicitly integrate indigenous plant knowledge with settlement-level land-use patterns in subtropical lowlands (Waheed *et al*., 2025). This gap limits understanding of how ecological change and socio-economic transitions shape adaptive plant use (Mubbin *et al*., 2025). To address this, we document and compare ethnobotanical diversity across five settlement types in District Kasur, Punjab. Specifically, we aim to (i) quantify plant-use diversity across settlement types, (ii) assess species overlap and settlement-specific contributions, and (iii) examine how land-use contexts structure ethnobotanical patterns.

MATERIALS AND METHODS

Study area

District Kasur (31°00′–31°25′ N, 74°10′–74°45′ E) lies immediately southeast of Lahore on the alluvial plains formed by the Ravi and Sutlej rivers and covers an area of 3,995 km² at altitudes ranging from 150–240 m above sea level (Figure 1) (Arshad *et al*., 2024). Geographically, the district forms part of the Sutlej basin, a major hydrological system that influences both agriculture and settlement distribution (Waheed and Arshad, 2024). The Ravi River flows along the northern boundary, while the Sutlej marks the southern extent, and together these rivers sustain extensive agricultural practices in an otherwise semi-arid plain environment (Waheed *et al*., 2022). The climate of Kasur is classified as moderate with distinct seasonal variation. Summers extend from May to September and are typically hot, with maximum daily temperatures exceeding 40 °C. Winters, from December to February, are mild to cool, with average temperatures ranging from 20 °C during the day to 6 °C at night. Mean annual precipitation is approximately 500 mm, of which nearly two-thirds occurs during the southwest monsoon (July–September) (Arshad *et al*., 2024). Kasur is primarily an agrarian district, with fertile alluvial soils supporting intensive rotations of maize (*Zea mays*), wheat (*Triticum aestivum*), turmeric (*Curcuma longa*), sugarcane (*Saccharum officinarum*), and rice (*Oryza sativa*) (Arshad *et al*., 2020). Livestock husbandry plays a complementary role, with households maintaining buffalo, cattle, goats, and sheep for milk, meat, and draft purposes. The population is predominantly Punjabi-speaking Muslim farming families, with a small Christian minority.

Data collection

Surveys were conducted from 2022 to 2024 across five settlement types representing distinct land-use contexts: forest, riverine, farmland, rural, and urban. Settlement categories were defined operationally based on dominant land cover, proximity to semi-natural habitats, and primary livelihood patterns. Forest settlements were located adjacent to or within remnant forest patches where access to wild vegetation was direct and frequent. Riverine settlements were situated along active river corridors and floodplains characterized by riparian vegetation and seasonally disturbed habitats. Farmland settlements were embedded within intensively cultivated agricultural landscapes dominated by croplands, field margins, and irrigation networks. Rural settlements represented village settings with mixed land use, including homegardens, smallholder fields, and communal lands, reflecting integrated wild and managed resource use. Urban settlements were defined by high infrastructural density, limited direct access to wild habitats, and reliance on managed green spaces and markets. Although some transitional characteristics occurred, settlements were classified according to their dominant land-use features to ensure analytical consistency. Sixty respondents were sampled from each settlement type, yielding a total of 300 participants. Both men and women were included, and demographic information on gender, age, education, and occupation was recorded to examine variation in ethnobotanical plant-use patterns among social groups. Ethnobotanical data were collected using open-ended interviews, semi-structured questionnaires, and casual conversation (Haq *et al*., 2023; Gillani *et al*., 2024). Interviews were centered around the range of plants that people locally know and utilize in their day-to-day activities, within categories like medicine, food, fodder, timber, vegetables, fruits, ornamentals, gum and dye sources, oilseeds, and insect repellents. Interviews requested information on the parts of plants used, preparation procedures, routes of administration, and ecological status (wild, cultivated, or semi-cultivated). Prior informed oral consent was obtained from all participants before data collection, and the study followed the International Society of Ethnobiology (2006) International Society of Ethnobiology Code of Ethics (with 2008 additions). Plant specimens cited by the respondents were taken on field walks, photographed in the field, and subsequently authenticated with the Flora of Pakistan. Specimens were cross-checked with taxonomic specialists if required. Botanical nomenclature was standardized based on Plants of the World Online (POWO; https://powo.science.kew.org/), ensuring conformity with up-to-date global taxonomy. Specimens were prepared and kept as vouchers for reference.

Data analysis

Data were examined to investigate both species diversity and distribution over settlement types and ethnobotanical knowledge structure within communities. Species richness and citation frequencies were tabulated per settlement type. Overlapping and singular contributions of species were represented in the form of Venn diagrams produced through the web-based tool accessible at https://bioinformatics.psb.ugent.be/cgi-bin/liste/Venn/calculate_venn.html. To investigate patterns of association between use categories and settlement types, multivariate analysis was conducted. Principal Component Analysis (PCA) was carried out with Factoextra package in R (Kassambara and Mundt 2017). PCA ordination had yielded a representation of how settlement types had grouped according to ethnobotanical knowledge and categories of plant use, as well as of the most differentiated domains of knowledge.

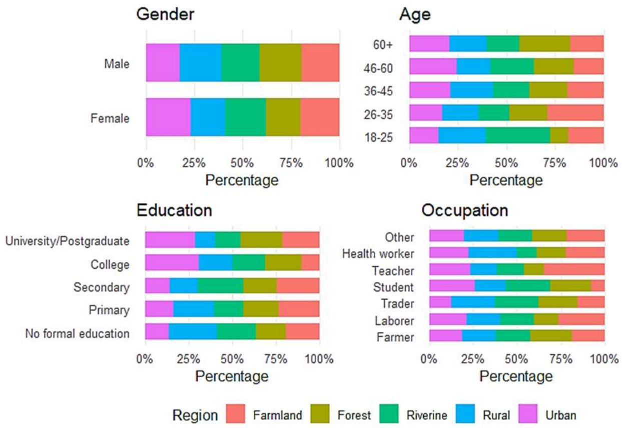

Fig. 2. Socio-demographic distribution of respondents across study regions. Stacked bar plots illustrate the relative percentages of participants by gender, age, education, and occupation across farmland, forest, riverine, rural, and urban areas.

RESULTS

Socio-demographic characteristics of respondents

The study involved 300 respondents representing five types of settlements namely farmland, forest, riverine, rural and urban (Figure 2). Gender distribution showed that there was a minor dominance of males (55.3 %, n = 166) over females (44.7 %, n=134). The greatest proportion included the respondents between the age of 36 and 45 years (28.7 %, n = 86), then 26 and 35 years (23.3 %, n = 70) (Supplementary Table S1). Participants with age above 60 years (n = 58) and those aged 46–60 years (n = 53) took up 19.3 % and 17.7 %, respectively. The least represented category (18–25 years) was the youngest (11%, n = 33), even though their representation was relatively larger in riverine regions than in other regions. The most common education level was on primary-level education (24.3%, n

= 73), then secondary-level education (23%, n = 69). Lack of formal schooling made 19.3% (n = 58), which is very high in the rural regions. University education was also less prevalent where 19.3% (n=58) had college or degree and only 14% (n=42) had university or postgraduate. The cities had the largest number of participants who had tertiary education, which indicated a relatively high access to education. The main occupation was farming, which has been reported by 30.7% (n = 92) respondents, and the other occupations are laborers (14%, n = 42) and traders (10.7%, n = 32). Other prominent groups were students (13%, n = 39), teachers (8.7%, n = 26) as well as health workers (6%, n = 18). Another 17% (n = 51) included the category of other occupations that represent other approaches to livelihood, not fitting into the main categories.

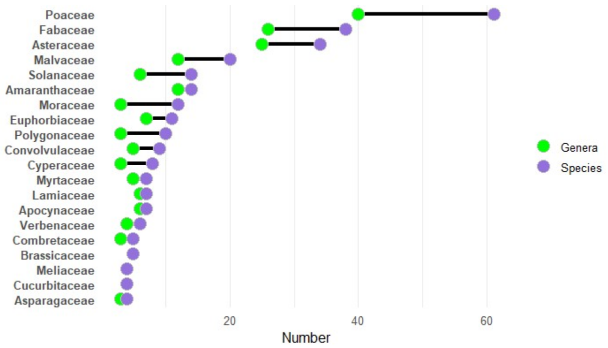

Fig. 3. Top 20 plant families recorded from District Kasur and adjoining areas, showing the number of genera (green) and species (purple) represented within each family.

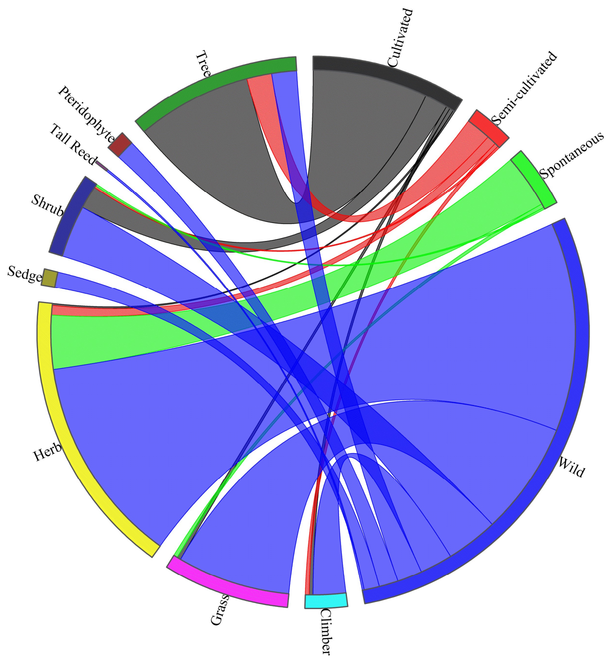

Fig. 4. Chord diagram illustrating the relationship between plant growth forms and habitat status in District Kasur and adjoining areas. The figure highlights the predominance of trees among cultivated taxa, the transitional role of semi-cultivated species, and the dominance of herbs and grasses within wild habitats.

Floristic composition and growth forms

A total of 373 species of plants were recorded as part of 257 genera and 69 families at District Kasur and its immediate surroundings in the ethnobotanical survey. Dicotyledons were the most common taxa, consisting of 278 species, monocotyledons (81 species) and pteridophytes (10 species) had rather limited numbers of taxa, and gymnosperms (4 species) constituted the smallest group (Supplementary Table S2). A significant amount of variation was present on the family level. Poaceae became the most diverse family (61 species and 40 genera), then Fabaceae (38 species and 26 genera), and Asteraceae (34 species and 25 genera). Other families that were significantly represented were; Malvaceae (20 species), Amaranthaceae (14 species), Solanaceae (14 species) and Moraceae (12 species) (Figure 3). Conversely, 19 families were monotypic with each family having one species. The recorded flora exhibits diverse growth forms highlighting the ecological heterogeneity of the area. Herbs formed the most important group (143 species; approximately 38 % of the entire flora) and then trees (86 species), grasses (63 species), and shrubs (41 species). Climbers (20 species) pteridophytes (9 species), sedges (6 species) and one tall reed species formed smaller proportions (Figure 4). Regarding the habitat status, wild species formed the majority (244 taxa) of the assemblage, 77 species were cultivated and 21 semi-cultivated, which represent the different levels of human management. There were also 31 other species that were found naturally in the anthropogenic habitats.

Ethnobotanical uses of documented flora

The most common category was medicinal use which was represented by 297 species. The second-largest group was found of the fodder plants (175 species) due to the intensive livestock subsistence economy of the area. The other significant applications were ornamental (80 species), soil binders (64 species), timber (48 species), and fruit and vegetable resources (23 species each). Other minor yet culturally notable uses were oilseed (10 species), gum source (10 species), culinary herbs (11 species) and dye (9 species), and insect-repellent plants (9 species). The first two principal components explained 71.2% of the total variation in ethnobotanical use categories (PC1 = 46.5%, PC2 = 24.7%; Figure 5). PC1 represents a primary gradient from wild, subsistence-oriented uses to managed and production-oriented uses. Medicinal species were positioned on the negative side of PC1, reflecting their strong association with foraging-based healthcare and reliance on semi-natural habitats, whereas fruits, vegetables, timber, ornamentals, oilseeds, dyes, gum sources, and insect-repellent plants clustered on the positive side, indicating greater management intensity and integration into cultivated or domesticated landscapes. PC2 reflects a secondary gradient separating functional ecological roles from culturally oriented uses.

Fodder species loaded strongly on the negative axis of PC2, emphasizing their structural and livelihood importance in agro-pastoral systems, while ornamentals and culturally valued categories occupied positive PC2 space, highlighting aesthetic and symbolic functions. Soil binder species occupied an intermediate position (positive PC1, slightly negative PC2), suggesting a transitional role between spontaneous vegetation and actively managed resources. The PCA reveals that ethnobotanical use categories are structured along gradients of land-use intensity, livelihood dependence, and cultural valuation rather than representing purely statistical groupings.

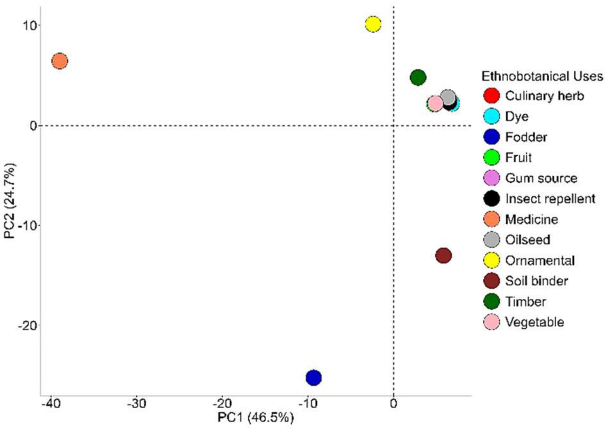

Fig. 5. Principal Component Analysis (PCA) ordination of ethnobotanical use categories.

Distribution of plant knowledge across settlement types

The highest count of unique species was recorded in the forest respondents (32), riverine (21) and farmland communities (18). Respondents in urban and rural settings provided relatively low number of exclusive species, 10 and 8 respectively. Even with these differences, there were very high overlaps with 13 species being reported in all the five types of settlements (Figure 6). Pairs compared in the form of overlaps revealed that the strongest overlaps were established between the forest and riverine respondents (32 species in common) and between forest and farmland respondents (24 species). 23 species were common between forest and rural communities and 15 between forest and urban groups. The respondents in the farmland and riverine reported 15 species in common, but overlap was lower than in rural-riverine (8 species), farmland-rural (4 species) and rural-urban (2 species) clusters. When settlement patterns were grouped together in three or more, larger trends were observed. Farmland, forest, and riverine communities all mentioned 28 species, whereas forest, riverine, and rural groups were 19 species. Forest, riverine, urban respondents had 13 species common, and farm land, forest and rural had 14 species. Smaller groups were farmland-forest-urban (9 species), farmland-riverine-urban (5 species), and rural-forest-urban (5 species). At greater degrees of overlap, 15 common species were shared between farm land, forest, riverine, and rural communities and 7 species shared between forest, riverine, rural and urban respondents.

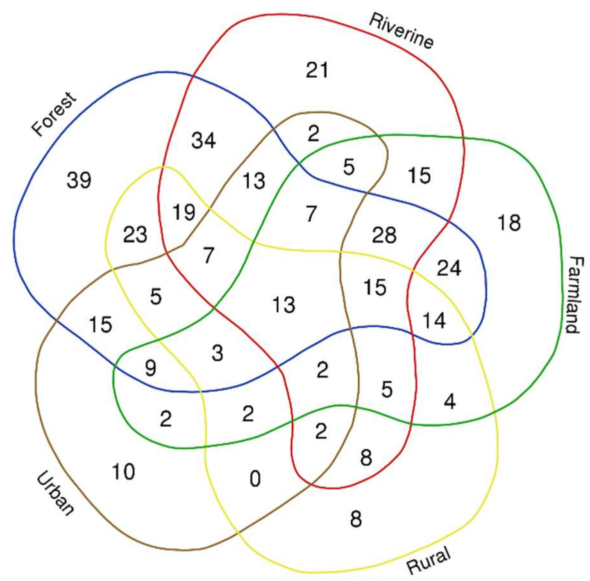

Fig. 6. Venn diagram showing the distribution and overlap of plant species reported across five settlement types. Colored outlines represent different settlement categories: forest (blue), riverine (red), farmland (green), rural (yellow), and urban (brown). Numbers within each section indicate species unique to or shared among settlement types.

Ethnobotanical prominence of plant species across settlements

The analysis revealed marked regional variation in the prominence of particular species. In forest areas, respondents most frequently cited *Cirsium falconeri*, *Lactuca serriola*, and *Rorippa indica*. Other highly recognized species included *Syzygium cumini*, *Tamarix aphylla*, *Agave americana*, *Asparagus officinalis*, and *Terminalia arjuna*. Riverine respondents emphasized a distinct suite of species, most notably *Euphorbia serpens*, *Senna occidentalis*, and *Callicarpa macrophylla*, each cited with near unanimity. Other prominent taxa included *Hibiscus rosa-sinensis*, *Persicaria glabra*, *Tripidium bengalense*, *Oroxylum indicum*, and *Alhagi maurorum*. In farmland areas, *Lactuca serriola* and *Euphorbia serpens* were the most frequently reported. *Terminalia arjuna* and *Taraxacum* sect. *Taraxacum* also achieved high recognition. Additional cited species included *Medicago sativa* and *Persicaria glabra*. Rural respondents reported a broader spectrum of culturally significant taxa, with *Dalbergia sissoo*, *Artemisia annua*, and *Taraxacum* sect. *Taraxacum* being nearly universally mentioned. High recognition was also given to *Stellaria media*, *Convolvulus arvensis*, *Plumeria rubra*, *Medicago sativa*, and *Grewia tenax*. The prominence of *Dalbergia sissoo* and *Plumeria rubra* reflects the central role of trees and shrubs in rural livelihoods. Urban respondents, though contributing fewer species overall, identified several taxa of continued importance, including *Syzygium cumini*, *Senna occidentalis*, *Dicliptera bupleuroides*, and *Dalbergia sissoo*. *Convolvulus arvensis* and *Plumeria rubra* were also widely acknowledged.

The principal component analysis (PCA) explained 66.2% of the total variation, with PC1 accounting for 41.5% and PC2 for 24.7%. Respondents from forest areas were clearly separated along the negative axis of PC1 (Figure 7). Riverine respondents were positioned in the negative quadrant of PC2. Farmland respondents were grouped on the positive side of PC1, close to the central axis of PC2. Rural respondents occupied the positive extremes of both PC1 and PC2, forming a distinct cluster. Urban respondents were located near the center of the ordination, with a slight shift toward the positive axis of PC2.

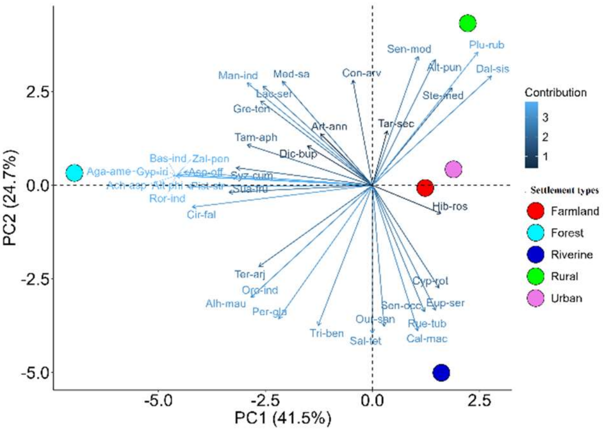

Fig. 7. Principal component analysis biplot showing the distribution of plant species knowledge as cited by respondents from five community types (farmland, forest, riverine, rural, and urban). Vectors represent plant species, with their length and orientation indicating the strength and direction of their contribution to community-level differentiation. Colored points correspond to the centroids of respondent groups, illustrating distinct clustering patterns according to the plants cited.

Medicinal species

A total of 297 medicinal plant records were documented across the five settlement types, representing 37 unique species groups distributed unevenly across habitats. Forest ecosystems exhibited the highest richness with 215 taxa, followed by farmland (162), riverine (150), rural (125), and urban settlements (89) (Figure 8a). Six species, *Tribulus terrestris, Cymbopogon iwarancusa, Withania somnifera, Grewia asiatica, Terminalia bellirica*, and *Solanum incanum*, were consistently present across all five settlement types. A notable number of species were shared among four habitats, such as *Medicago sativa, Xanthium strumarium, Digera muricata, Taraxacum sect. Taraxacum, Sonchus oleraceus, Cichorium intybus,* and *Ricinus communis* (Farmland–Forest–Riverine–Rural), and *Morus alba, Morus nigra,* and *Brassica juncea* (Farmland–Forest–Riverine–Urban). Similarly, overlaps among three habitats highlighted ecologically resilient species including *Terminalia arjuna, Mentha arvensis, Chenopodiastrum murale,* and *Artocarpus lacucha* (Farmland–Forest–Riverine), as well as *Chukrasia tabularis, Tagetes erecta, Melia azedarach, Cyperus rotundus,* and *Rumex crispus* (Forest–Riverine–Rural).

Despite these overlaps, each habitat also maintained distinct assemblages of medicinal flora. Forest areas supported 33 exclusive taxa, including *Verbesina encelioides, Casuarina equisetifolia, Ficus religiosa, Lantana camara, Butea monosperma,* and *Agave americana*, underscoring their role as reservoirs of unique ethnobotanical resources. Riverine zones contributed 17 unique species, such as *Ficus benghalensis, Vachellia nilotica, Ficus elastica, Eucalyptus microtheca*, and *Ipomoea aquatica*, reflecting adaptations to moist and riparian conditions. Farmlands harbored 14 exclusive species, including *Solanum virginianum, Sida acuta, Rhynchosia minima,* and *Portulaca oleracea*. Rural habitats maintained 8 distinct species, such as *Yucca aloifolia, Cissampelos pareira,* and *Morus serrata*, while urban areas, although the least diverse, sustained 10 unique taxa, including *Pulicaria undulata, Helianthus annuus, Erigeron bonariensis,* and *Citrus trifoliata*.

Fodder species

Forest areas contributed the highest richness (87 species), followed by riverine (73 species), farmland (60 species), rural (43 species), and urban (26 species). Several species were consistently shared across four settlement types (Figure 8b). For instance, *Morus nigra*, *Morus alba*, *Digera muricata*, and *Malva parviflora* were used in farmland, forest, riverine, and urban areas. Similarly, *Urochloa deflexa*, *Bothriochloa ischaemum*, *Sorghum halepense*, and *Urochloa ramosa* were prominent in forest, riverine, rural, and urban contexts. Certain species were restricted to three settlement types, For example, *Trifolium resupinatum*, *Persicaria glabra*, *Boerhavia procumbens*, *Echinochloa crus-galli*, and *Poa pratensis* were shared between farmland, forest, and riverine areas, while *Fimbristylis quinquangularis*, *Melilotus officinalis*, *Rumex crispus*, and *Saccharum spontaneum* occurred in forest, riverine, and rural areas. Likewise, *Amaranthus viridis*, *Dactyloctenium aegyptium*, *Bothriochloa bladhii*, *Ziziphus jujuba*, and *Aristida mutabilis* were important in farmland, forest, and rural settlements.

Fewer species were recorded exclusively in two settlement types, such as *Cenchrus ciliaris* and *Phragmites karka* in forest and riverine areas, or *Carex fedia* and *Marsilea quadrifolia* in forest and urban zones. Species like *Sida rhombifolia*, *Alhagi maurorum*, *Ziziphus nummularia*, *Setaria viridis*, and *Rumex spinosus* were

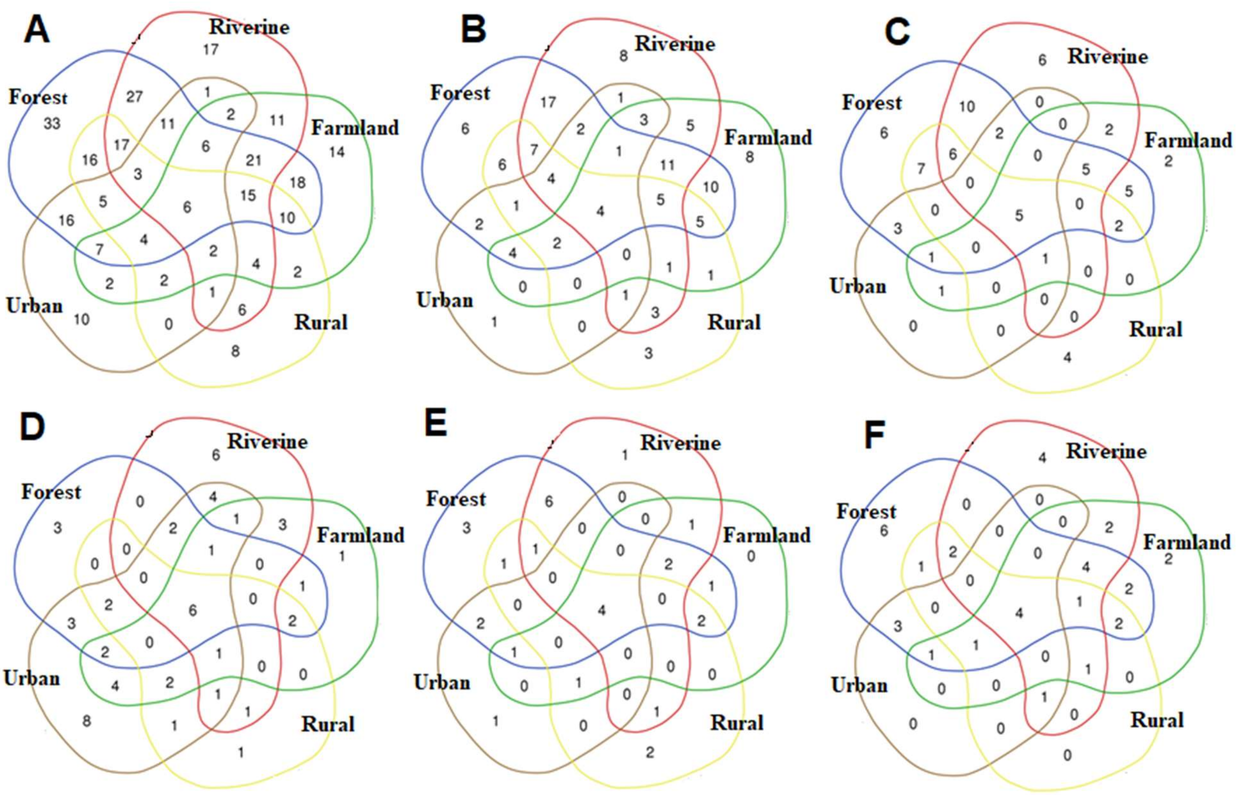

Fig. 8. Venn diagrams showing the distribution and overlap of plant species among five settlement types (forest = blue, riverine = red, farmland = green, rural = yellow, urban = brown) for different ethnobotanical use categories: **A.** medicinal, **B.** fodder, **C.** timber, **D.** ornamental, **E.** fruit, and **F.** vegetable species. In each panel, circles represent settlement types, and numbers indicate species unique to or shared among settlements. Overlapping regions show taxa reported from multiple settlement types, whereas non-overlapping sections represent settlement-specific species.

restricted to forest and riverine areas. Interestingly, some fodder plants were confined to single settlement types, representing unique ecological adaptations or localized ethnobotanical knowledge. For example, *Lathyrus aphaca*, *Lolium persicum*, *Chrysopogon aucheri*, and *Avena fatua* were exclusively cited in farmland areas, while *Cocculus hirsutus*, *Cissampelos pareira*, and *Morus serrata* were reported only in rural zones. Urban use was limited to species like *Launaea procumbens*.

Timber species

Among timber-yielding plants, forest areas recorded the highest richness with 52 species, followed by riverine zones with 37, rural settlements with 25, farmland with 24, and urban areas with 13. A small group of species was consistently cited across almost all settlement types (Figure 8c). For instance, *Morus nigra, Morus alba, Grevillea robusta, Terminalia bellirica,* and *Neltuma juliflora* were shared between farmland, forest, riverine, rural, and urban settlements. Similarly, *Dalbergia sissoo* was reported from four settlements (farmland, riverine, rural, and urban). Several taxa were distributed among three settlement types, including *Toona ciliata, Artocarpus lacucha, Tecomella undulata, Terminalia arjuna,* and *Pinus roxburghii* (farmland, forest, and riverine); and *Chukrasia tabularis, Tamarix aphylla, Mallotus nudiflorus, Melia azedarach, Ficus rubiginosa,* and *Albizia lebbeck* (forest, riverine, and rural). Notably, *Triadica sebifera* and *Bombax ceiba* were shared between forest, riverine, and urban areas, while *Ficus virens* and *Ziziphus jujuba* occurred in farmland, forest, and rural settlements.

Two-settlement associations were also prominent, *Aegle marmelos, Conocarpus erectus, Ziziphus nummularia, Oroxylum indicum, Salvadora persica, Psidium guajava, Tamarix indica, Leucaena leucocephala, Salix tetrasperma,* and *Populus nigra* were shared between forest and riverine areas, while *Ficus racemosa, Taxodium distichum, Salix alba, Prosopis cineraria,* and *Parkinsonia aculeata* were restricted to farmland and forest. In rural areas, species such as *Vachellia farnesiana, Senegalia modesta, Azadirachta indica, Pongamia pinnata, Neltuma glandulosa, Mangifera indica*, and *Celtis australis* were shared with forests, while urban respondents highlighted *Senegalia senegal, Syzygium cumini*, and *Salvadora oleoides*. Several species were restricted to single settlement types. In forests, taxa such as *Casuarina equisetifolia, Bauhinia purpurea, Jacaranda mimosifolia, Butea monosperma, Alstonia scholaris,* and *Ficus religiosa* were exclusively cited. Riverine areas showed unique reliance on species including *Ficus benghalensis, Vachellia nilotica, Ficus elastica, Lagerstroemia indica, Eucalyptus microtheca,* and *Bauhinia variegata*. Farmland contributed two unique species, *Araucaria cunninghamii* and *Corymbia citriodora*, while rural areas recorded *Albizia procera, Eucalyptus camaldulensis, Morus serrata*, and *Tamarix dioica*. Urban reliance was limited to *Pterospermum acerifolium*, emphasizing highly localized availability.

Ornamental species

Urban areas supported the highest diversity of ornamental plants with 38 species, followed by riverine settlements with 26, farmland with 24, forest areas with 22, and rural settlements with 17 (Figure 8d). In farmland areas, distinctive taxa included *Platycladus orientalis*, alongside commonly planted ornamentals such as *Taxodium distichum*, *Nerium oleander*, and *Melaleuca citrina*. Farm households also maintained visually prominent species like *Hibiscus rosa-sinensis* and *Bougainvillea spectabilis*, which were shared with other settlement types. Forest settlements, dominated by shade and boundary ornamentals. *Helianthus annuus*, *Citrus trifoliata*, and *Hamelia patens* were restricted to these areas, while shared species such as *Grevillea robusta* and *Araucaria cunninghamii* were cultivated in both forest and other settlement types. Trees such as *Saraca asoca*, *Cassia fistula*, and *Cascabela thevetia*. Riverine settlements, of which *Ficus benghalensis*, *Ficus elastica*, *Bauhinia variegata*, *Lagerstroemia indica*, *Bambusa multiplex*, and *Ruellia tuberosa* were restricted to these habitats. Shared species included *Triadica sebifera* and *Ouret sanguinolenta*, also valued in forest and urban contexts. Rural settlements were characterized by comparatively low richness, with only a few ornamentals exclusive to this category, notably *Yucca aloifolia*. However, rural areas shared *Tagetes minuta*, *Combretum indicum*, and *Epipremnum aureum* with farmland and urban areas. The presence of *Senna alata* and *Dombeya spectabilis*, shared with forest and urban areas. Urban areas displayed the highest richness and contained the majority of exclusive ornamentals, including *Plumeria obtusa*, *Jacaranda mimosifolia*, *Agave americana*, *Butea monosperma*, *Tecoma stans*, *Canna indica*, and *Bauhinia purpurea*. In addition, urban settlements shared key ornamentals such as *Grevillea robusta* and *Excoecaria cochinchinensis* with farmland and forest areas, while simultaneously integrating species like *Conocarpus erectus*, *Carissa carandas*, and *Punica granatum*, also valued in riverine contexts.

Fruit species

Forest areas recorded the highest number of fruit plants with 23 species, followed by riverine settlements with 16, farmland and rural areas with 12 each, and urban areas with 9 (Figure 8e). *Terminalia bellirica*, *Morus nigra*, *Morus alba*, and *Grewia asiatica* were common to farmland, forest, riverine, rural, and urban areas. Similarly, *Artocarpus lacucha* and *Physalis angulata* were recorded from farmland, forest, and riverine settlements, while *Trichosanthes cucumerina* was shared among forest, riverine, and rural contexts. More localized overlaps included *Ziziphus jujuba* and *Citrus medica* (farmland, forest, rural), *Ficus auriculata* (farmland, forest, urban), and *Lycium depressum* (farmland, rural, urban). *Aegle marmelos*, *Punica granatum*, *Psidium guajava*, *Carissa carandas*, *Salvadora persica*, and *Ziziphus nummularia* were particularly prominent in both forest and riverine areas. Meanwhile, *Mangifera indica* was shared between forest and rural settlements, whereas *Salvadora oleoides* and *Syzygium cumini* linked forest and urban contexts. A few species showed narrower distributions: *Ficus racemosa* occurred in farmland and forest; *Ficus palmata* in farmland and riverine; and *Ziziphus spina-christi* in riverine and rural zones. Some species were uniquely restricted to a single settlement type. For example, *Solanum nigrum*, *Lycium shawii*, and *Physalis halicacabum* were found exclusively in forest areas, while *Coccinia grandis* was confined to riverine areas. Rural communities cited *Morus serrata* and *Grewia tenax*, and urban informants uniquely referred to *Citrus trifoliata*.

Vegetable species

Forest areas exhibited the highest richness of vegetable species with 27 unique taxa, followed by farmland (20 species), riverine settlements (19 species), rural areas (13 species), and urban areas (10 species) (Figure 8f). Several species were common across all five settlement types, including *Brassica juncea*, *Cichorium intybus*, *Digera muricata*, and *Lactuca serriola*. *Medicago sativa* was reported from farmland, forest, and rural settlements. Species present in four settlement types included *Sisymbrium irio* (farmland, forest, rural, urban), *Mentha arvensis*, *Artocarpus lacucha*, *Physalis angulata*, and *Chenopodium album* (farmland, forest, riverine), *Melilotus officinalis* and *Trichosanthes cucumerina* (forest, riverine, rural), *Citrullus colocynthis* and *Amaranthus viridis* (farmland, forest, rural), *Mentha longifolia* (farmland, forest, urban), *Stellaria media* (farmland, riverine, rural), and *Nasturtium officinale* (riverine, rural, urban).

Species confined to two settlement types included *Alternanthera sessilis* and *Trianthema portulacastrum* (farmland, forest), *Vicia sativa* (forest, rural), *Asparagus officinalis*, *Marsilea quadrifolia*, and *Urtica urens* (forest, urban), as well as *Melilotus indicus* and *Moringa oleifera* (farmland, riverine). Exclusive taxa were also recorded. Forest settlements uniquely supported *Bauhinia purpurea*, *Physalis halicacabum*, *Marsilea minuta*, *Solanum nigrum*, *Rorippa indica*, and *Oxalis corniculata*. Riverine areas cited *Coccinia grandis*, *Ipomoea aquatica*, *Bauhinia variegata*, and *Anethum graveolens*. Farmland respondents reported *Portulaca oleracea* and *Rhynchosia minima* as unique species.

DISCUSSION

The socio-demographic profile aligns with broader ethnobotanical patterns in South Asia and beyond. A modest male predominance likely reflects gendered access to public spaces and interviewing, yet it is less skewed than reports from Hasilpur, where male participation was overwhelming, suggesting comparatively fewer social barriers in Kasur (Wang *et al*., 2025). The concentration of respondents in mid-life and older cohorts is consistent with evidence that plant knowledge accumulates with age and is differentially structured by gender and life stage (Müller *et al*., 2015). Education gradients also fit prior work: primary and lower-secondary schooling often coexist with strong practical knowledge, while tertiary education clusters in urban areas where formal employment competes with time for resource-based learning (Ramzan *et al*., 2024; Wang *et al*., 2025). Farming as the dominant livelihood explains the breadth of utilitarian knowledge, paralleling food-medicine continuums documented across Pakistani communities (Abdin *et al*., 2022; Ramzan *et al*., 2024). Occupation- and age-linked differences echo agri-practice stratification seen in Benin, underscoring how socio-demographics shape management and knowledge transmission (Azon *et al*., 2023; Sheng *et al*., 2024a).

The high floristic richness recorded in District Kasur reflects the ecological heterogeneity and strong human–environment interaction typical of subtropical lowland agroecosystems. The dominance of dicotyledons and herbaceous taxa indicates adaptation to varied microhabitats and seasonal dynamics, consistent with findings from diverse agroecological landscapes where human management enhances compositional complexity (Ávila-Bello *et al*., 2024; Fan *et al*., 2025). The pre-eminence of Poaceae, Fabaceae, and Asteraceae mirrors patterns observed in tropical and subtropical agroecosystems, where these families provide multifunctional species valued for fodder, food, and soil fertility improvement (Abraham *et al*., 2022; Xu *et al*., 2025). Similar to observations in smallholder homegardens in China (Hou *et al*., 2024; Luo *et al*., 2024), the coexistence of cultivated and spontaneous species in Kasur highlights the relations between intentional cultivation and natural regeneration processes. Herbs and grasses dominate the wild assemblage, emphasizing both ecological resilience and ease of access for subsistence uses. The coexistence of trees, shrubs, and climbers contributes to vertical stratification analogous to the structural layering described in agroforestry systems of Madagascar (Mariel *et al*., 2021; Huang *et al*., 2025). This compositional diversity not only supports ecosystem services, such as fodder provision, soil stabilization, and microclimate regulation, but also signifies the embedded traditional ecological knowledge that enables communities to maintain multifunctional landscapes under changing environmental and socio-economic pressures.

The predominance of medicinal plants reflects strong reliance on ethnopharmacological practices for primary healthcare and positions medicine along the wild, subsistence-oriented end of the primary PCA gradient, highlighting continued dependence on semi-natural habitats for therapeutic resources (Ramzan *et al*., 2024; Wang *et al*., 2025). Likewise, fodder species load toward the functional extreme of the secondary axis, emphasizing their central role in agro-pastoral livelihoods where livestock and cropping systems are tightly integrated (Harun *et al*., 2017; Abraham *et al*., 2022). In contrast, fruits, vegetables, timber, ornamentals, oilseeds, and related categories cluster toward the managed and production-oriented end of PC1, reflecting increasing land-use intensity and integration into cultivated landscapes. The positive association of ornamentals and culturally valued taxa along PC2 indicates a shift from purely functional ecological roles toward aesthetic and symbolic uses. Soil binder species occupy an intermediate position in ordination space, suggesting a transitional role between spontaneous vegetation and actively managed resources. Together, these patterns demonstrate that ethnobotanical use categories are structured along gradients of habitat access, management intensity, and cultural valuation, revealing how livelihood strategies and land-use mosaics jointly organize plant-use systems in subtropical lowlands (Mariel *et al*., 2021; Ávila-Bello *et al*., 2024; Hou *et al*., 2024). The overlapping yet distinct ethnobotanical profiles across forest, riverine, farmland, rural, and urban areas underscore the interplay between habitat heterogeneity and cultural adaptation. Similar to Luo *et al*. (2024), inter-settlement overlaps signify knowledge exchange fostered by proximity and trade, while exclusive taxa in forest and riverine zones highlight ecological specialization and site-specific ethnobotanical expertise. This spatial partitioning of plant knowledge aligns with earlier findings from Qureshi *et al*. (2007) and Umair *et al*. (2019), affirming that environmental gradients and cultural practices jointly sustain ethnobotanical diversity, reinforcing the resilience and cultural continuity of indigenous agroecosystems in subtropical Punjab.

The settlement-specific prominence patterns reflect how ecology, access, and livelihood jointly structure plant knowledge. Forest-centered salience of taxa such as *Cirsium falconeri, Rorippa indica*, and *Terminalia arjuna* points to foraging in semi-natural microhabitats where medicinal and multipurpose trees remain accessible; similar riparian specializations have been documented for riverine communities along the Chenab, where hydrological disturbance selects for distinctive, highly cited species (Umair *et al*., 2019; Zhang *et al*., 2024). Riverine consensus around *Euphorbia serpens, Senna occidentalis*, and *Callicarpa macrophylla* mirrors this filter, while farmland emphasis on *Lactuca serriola, Medicago sativa*, and *Taraxacum spp*. aligns with agro-pastoral practice and curated field margins, patterns consistent with fodder- and remedy-oriented floras across Punjab (Harun *et al*., 2017; Usman *et al*., 2021). In rural settlements, the prominence of *Dalbergia sissoo* and *Plumeria rubra* underscores the centrality of timber, shade, and ritual species to household economies, echoing earlier regional inventories that tie arboreal taxa to everyday material culture and care (Qureshi *et al*., 2007; Malik *et al*., 2015). Urban profiles, though narrower, retain culturally valued trees (e.g., *Syzygium cumini*) and resilient weeds (e.g., *Convolvulus arvensis*), consistent with emerging evidence that disturbed cities can still host robust medicinal-knowledge cores (Ullah *et al*., 2025). *Terminalia arjuna* and *Mentha arvensis* behave as "bridge taxa," linking settlements through shared therapeutic or fodder functions, a pattern also seen in cross-cultural food–medicine continua where overlap increases with trade, kinship, and seasonal labor mobility (Waheed *et al*., 2023; Malik *et al*., 2024). Habitat-specific exclusives in forests, riverine corridors, and farmlands demonstrate environmental filtering and localized experimentation, key engines of ethnobotanical diversification and high informant consensus around context-appropriate remedies (Yaseen *et al*., 2019; Usman *et al*., 2021).

Fodder patterns in Kasur mirror low-input pastoral strategies across Pakistan: high richness in forests and riverine belts, broad overlaps among settlements, and pockets of site-specific taxa that reflect grazing regimes, water availability, and cut-and-carry practices. The recurrent citation of Poaceae and associated grasses parallels regional rankings of palatable forages and ethnoveterinary relevance (Harun *et al*., 2017; Shaheen *et al*., 2020; Rahman *et al*., 2022). Exclusive farmland grasses (e.g., *Avena fatua*) and field-margin herbs illustrate farmer-led selection for seasonal feed, consistent with local prioritization and conservation concerns documented in the same district (Arshad *et al*., 2022). Timber distributions show a parallel ecology–economy logic: forests and riverine corridors concentrate multipurpose woods, while rural and urban areas retain serviceable, fast-growing trees for fuel, shade, and construction. These configurations echo market and household preferences reported from northern wood markets and mountain valleys, where a few durable species dominate trade while pressure on vulnerable taxa necessitates targeted protection (Jan *et al*., 2011; Shah *et al*., 2014). Urban dominance in ornamentals, alongside distinctive forest and riverine ornamentals, underscores cultural curation and microclimatic filtering. Such mosaics align with observations that household plantings integrate aesthetics, shade, and symbolic value, while also buffering heat and dust. Fruit and vegetable portfolios reveal a food–medicine continuum spanning settlements. Shared species (e.g., *Morus* spp., *Terminalia bellirica*) act as nutritional and therapeutic keystones, whereas habitat-restricted edibles track water tables and soil textures. These patterns resonate with evidence that wild and semi-wild vegetables and fruits persist as critical, teachable resources for diet diversification, income, and primary healthcare (Abbasi *et al*., 2013; Ahmad *et al*., 2019; Abbas *et al*., 2020; Jabeen *et al*., 2024).

The findings demonstrate that plant-use diversity in Kasur is structured by ecological context and livelihood integration, highlighting the need for management strategies that recognize habitat heterogeneity and community knowledge. Forest and riverine systems, rich in medicinal and timber species, require participatory conservation programs that combine traditional ecological knowledge with restoration of degraded habitats. Agro-pastoral landscapes should prioritize cultivation of high-value fodder grasses and multipurpose trees to sustain livestock productivity and reduce pressure on wild flora (Harun *et al*., 2017; Arshad *et al*., 2022). Community-based nurseries and rotational grazing schemes can further enhance regeneration and species resilience. Urban areas, though species-poor, offer potential for green infrastructure through home gardens, ornamental plantings, and awareness programs to preserve ethnobotanical heritage (Ullah *et al*., 2025). Integrating traditional healers and local farmers into biodiversity monitoring can ensure equitable benefit-sharing and continuity of indigenous knowledge. Cross-settlement exchange networks for seeds and seedlings would also reinforce regional floristic connectivity.

Implications for conservation and management

The observed settlement-specific patterns of plant use have direct implications for conservation and land management in District Kasur. Forest and riverine settlements function as key reservoirs of medicinal, fodder, and timber species and should therefore be prioritized for habitat protection and restoration, particularly under increasing pressure from agricultural expansion, urban growth, and riverbank modification. Farmland and rural landscapes, which integrate cultivated and semi-wild taxa, provide opportunities for promoting agroforestry, field margin conservation, and the cultivation of multipurpose native species to reduce harvesting pressure on wild populations. Urban areas, although comparatively species poor, retain culturally important ornamentals and fruit trees and could contribute to biodiversity conservation through home gardens and urban greening initiatives. Community-based management strategies, including participatory reforestation, local nurseries for medicinal and fodder plants, and knowledge sharing networks among settlements, could strengthen regional plant connectivity while supporting local livelihoods. Integrating indigenous knowledge into local development planning may therefore enhance both biodiversity conservation and social ecological resilience in Kasur's rapidly changing lowland landscape.

CONCLUSION

The ethnobotanical evidence highlights a dynamic interplay between ecological diversity, cultural adaptation, and livelihood dependence. Across forest, riverine, farmland, rural, and urban settlements, patterns of plant use show how communities skillfully adapt and draw on local flora to meet needs for medicine, fodder, food, and materials. Forest and riverine areas function as biodiversity reservoirs supporting rich medicinal and timber assemblages, whereas farmlands and rural settlements integrate domesticated and semi-wild taxa to sustain livelihoods. Urban zones, though comparatively species-poor, maintain key cultural and medicinal species that preserve ethnobotanical continuity in changing environments. The convergence of shared species across habitats illustrates interconnected ecological networks and regional knowledge exchange, while habitat-specific taxa emphasize localized adaptation and stewardship. The results point to the need for conserving biocultural landscapes through collaborative management, reforestation with native multipurpose species, and careful documentation of indigenous knowledge before it fades amid the pressures of modernization. Strengthening traditional resource governance, integrating ethnobotanical insights into rural development planning, and promoting education on sustainable plant use will be critical for maintaining ecosystem services and cultural resilience.

ACKNOWLEDGMENTS

This article is part of the PhD thesis of Mr Muhammad Waheed. We acknowledge the Department of Botany, University of Okara for providing resources for the conducting this project.

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