Research Article

Medicinal Plant Diversity and Ethnobotanical Applications in Tehsil Khall, Dowab, Dir Lower, Khyber Pakhtunkhwa

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Abstract | This study aims to document floral diversity and associated ethnobotanical knowledge in Tehsil Khall, Village Dowab, District Dir Lower, Khyber Pakhtunkhwa, Pakistan. A total of 58 plant species belonging to 34 families and 48 genera were recorded, with Rosaceae as the dominant family, followed by Papilionaceae, Poaceae, and Moraceae. Herbs were the most prevalent life form (55.88%), while trees and shrubs each accounted for 22.05%. Seasonal analysis indicated that most species were available in spring (96%), followed by summer (84%), autumn (64%), and winter (64%), highlighting the ecological suitability of the region. Ethnobotanical data revealed that local communities extensively depend on plant resources for daily needs, with 40% of species used as fuelwood, followed by fodder (20%), furniture (16%), and vegetables (16%), while smaller proportions were used for shelter and ornamental purposes. From a medicinal perspective, 58 species belonging to 41 families and 50 genera were documented, with Lamiaceae as the leading family, followed by Euphorbiaceae and Apiaceae. Leaves were the most commonly used plant part (approximately 25%), whereas whole plants, roots, and fruits were also frequently utilized. The most common medicinal application was for treating cough, followed by anthelmintic, diuretic, and carminative uses. Overall, the findings highlight the rich plant diversity of the study area and emphasize the significant role of traditional ethnobotanical knowledge in supporting local livelihoods, primary healthcare, and biodiversity conservation.

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Introduction

Lower Dir constitutes the southern segment of the former Dir district. Historically, before the independence of Pakistan, Dir was governed by Nawab Shah Jehan Khan as an autonomous princely state (Martin, 1995; Ullah, 2024). The region was formally integrated into Pakistan in 1969 and subsequently designated as a district in 1970. In 1996, administrative reforms led to its division into Upper Dir and Lower Dir (Abel and Busia, 2005). Geographically, District Lower Dir is located in the northwestern part of Khyber Pakhtunkhwa province, covering an area of approximately 1,583 km^2 (Bekele and Reddy, 2015). The terrain is predominantly rugged and mountainous, except for certain southwestern plains (Ahmad *et al*., 2011). The district is bounded by Swat District to the east, Afghanistan to the west, Upper Dir and Chitral to the north and northwest, and Malakand and Bajaur Agency to the south (Khan *et al*., 2012). Administratively, Lower Dir is divided into six tehsils, which are further subdivided into 37 union councils (Abel and Busia, 2005). The district is represented in the provincial assembly by five elected members (Ahmad *et al*., 2011). The most direct route connecting Lower Dir to the provincial capital, Peshawar, passes through Charsadda and Malakand districts (Ajaib *et al*., 2014). Alternatively, access from other parts of the country is commonly via Mardan and Malakand (Ajaib *et al*., 2013). Notably, the district lacks railway connectivity, which further emphasizes its relatively remote and mountainous nature (Albuquerque, 2010).

The landscape of the district is predominantly characterized by hills and mountains belonging to the southern ranges of the Hindu Kush (Bekele and Reddy, 2015). In general, these mountain ranges extend from north to south, with the highest peaks in the northern upper region exceeding 3000 meters in elevation (Betti, 2004). The central part of the district has an elevation ranging from 1800 to 2000 meters, while it gradually declines to approximately 600 meters in the southern areas near the confluence of the Panjkora and Swat Rivers (Choudhary *et al*., 2008; Chhetri, 2009). The Panjkora River and its tributaries have deeply incised these mountainous terrains, forming narrow valleys where most of the population resides and practices agriculture (Cotton, 1996). Although rivers and nallahs provide abundant water resources, their utilization for agriculture remains limited due to the steep mountainous terrain along the riverbanks (Cox and Balick, 1994). Major valleys of the district include Timergara, Jandool, Maidan, Samarbagh, Asban, and Adenzai (Farnsworth, 1988; Devi and Muniyandi, 2015). The climate of the region is generally temperate during summer, although the months of June and July are comparatively hot (Dolatkhahi *et al*., 2014). The mean maximum temperature in June is recorded at 32.52 °C, while the mean minimum temperature is approximately 15.67 °C (Farnsworth, 1993). During spring, strong and cold windstorms locally known as *Badama*, originating from Lowari Top, occur in the afternoons and are often severe and uncomfortable (Foo *et al*., 2016).

Winter in the district is harsh and cold, with temperatures declining significantly from November onward (Francis, 2009). December marks the onset of severe winter, while January and February are the coldest months, during which temperatures frequently fall below freezing point (Garcia *et al*., 2007). The mean maximum and minimum temperatures in January have been recorded at approximately 1.22 °C and below freezing, respectively (Gilani *et al*., 2013). The region receives precipitation throughout the year; however, due to western disturbances, winter rainfall is higher than in summer (Gilani *et al*., 2007). The highest recorded monthly rainfall was approximately 242.22 mm in March (Goodman and Ghafoor, 1995). Relative humidity remains comparatively high throughout the year (Hassan *et al*., 2015). Ethnobotany is the study of interactions between humans and plants, with particular emphasis on traditional and tribal cultures (Hassan *et al*., 2015). According to the World Health Organization (WHO), approximately 65–80% of the population in developing countries relies primarily on plant-based resources for their basic healthcare needs due to limited access to modern medical facilities and economic constraints (Hazrat *et al*., 2007). Although traditional knowledge of plant use predates human civilization, the term *ethnobotany* was first introduced in 1896 by the American botanist John W. Harshberger to describe the study of plants used by indigenous and primitive societies (Hazrat *et al*., 2011).

Over time, ethnobotany has emerged as a significant scientific discipline aimed at uncovering the diverse uses of plants and their role in human life (Hazrat *et al*., 2011). It broadly includes various aspects of human–plant interactions, often summarized through four key components: people, plants, interactions,

and uses (Hazrat *et al*., 2015). The use of medicinal plants for treating diseases dates back thousands of years, forming the basis of traditional healthcare systems (Henry *et al*., 2013). Therefore, investigating indigenous knowledge of medicinal plants has become increasingly important for developing effective strategies for the conservation and sustainable use of biological resources (Hilary *et al*., 2005). Although ethnobotanical research addresses the full spectrum of human–plant relationships, it has primarily focused on plants used for food and medicine (Hussain *et al*., 2008; Homervergel and Kim, 2014).

A large number of drugs used to treat various human diseases are derived from plants. Historically, plants served as the primary source of therapeutic remedies, whether in the form of crude plant parts or more refined preparations such as extracts and mixtures (Iain *et al*., 2005). Even today, many modern pharmaceuticals are plant-derived and remain effective against a wide range of diseases (Ibrar *et al*., 2007). In many developing countries, indigenous communities, particularly in rural areas, continue to rely on medicinal plants due to their accessibility and traditional knowledge systems (Iiengme, 1983). Plants, especially higher plants, are often regarded as "sleeping giants" of drug discovery because of their rich reservoir of bioactive compounds, which have been extensively investigated for their pharmacological potential (Islam *et al*., 2013).

Ethnobotany plays a crucial role in documenting and preserving this traditional knowledge, focusing on the direct interactions between humans and plants within non-industrialized societies (Jain, 1965). The global reliance on herbal medicine has also increased significantly. For instance, approximately 38 million adults in the United States used herbal treatments in 2002, making it one of the most widely practiced complementary and alternative medicine (CAM) modalities. The use of herbal medicine increased from 12.1% in 1997 to 18.6% in 2002 (Jamila and Rahman, 2016). Correspondingly, the global market for herbal products has expanded dramatically, rising from $200 million in 1988 to $3.5 billion in 1997 and reaching $4.4 billion in 2005 (Jan *et al*., 2011). This trend reflects what has been described as an "herbal renaissance," driven by advances in pharmacological research, improved scientific understanding of medicinal compounds, and increased public acceptance of natural therapies (Jem *et al*., 2014). Plants and humans share a deep and longstanding relationship, and ethnobotanical research continues to explore medicinal plant resources for treating diseases such as inflammation, cancer, and AIDS (Jeruto *et al*., 2008). Compared to animals, plants play a more significant role in daily human life due to their abundance of biologically active compounds capable of treating various ailments (Kaigongi and Musila, 2015). It is estimated that approximately 30% of modern medicines have been developed from plant-based sources, and the demand for herbal remedies is expected to increase further as interest in natural products grows globally (Kalle and Sõukand, 2012; Kaingua *et al*., 2014). Traditional medicine utilizes a wide range of plant species for treating skin diseases such as ringworm, scabies, leucoderma, and eczema, as well as infections caused by bacteria, fungi, and viruses (Kamau *et al*., 2016). Medicinal plants represent valuable natural resources, providing diverse chemical compounds for therapeutic and industrial applications. However, traditionally, medicinal plants are defined as species locally used to treat diseases or as raw materials for pharmaceutical development (Khan *et al*., 2012; 2015). Therefore, the documentation and conservation of such plant resources are essential to ensure the sustainable availability of bioactive compounds for future generations (Khan *et al*., 2013). The present study was designed with three main objectives. First, to systematically document the floral diversity of Tehsil Khall, Village Dowab, District Dir Lower, Khyber Pakhtunkhwa, including plant species, families, genera, growth forms, and seasonal distribution. Second, to investigate and record the ethnobotanical uses of these plants, highlighting their importance in local livelihoods as fuelwood, fodder, food, furniture, shelter, and other daily applications. Third, to explore the ethnomedicinal potential of the documented flora by identifying key species, plant parts used, and common therapeutic applications. This study contributes to the preservation of indigenous knowledge and provides a baseline for future pharmacological research and biodiversity conservation efforts.

Materials and Methods

Study area selection

An ethnobotanical survey was conducted during the summer of 2017 in selected villages of Tehsil Khall, District Dir Lower, Khyber Pakhtunkhwa, Pakistan. The surveyed locations included Dowab, Barkaly

Charamab, Lalo, Safaray, and Sultan Abad (Mahmood *et al*., 2011). These areas were selected based on their rich plant diversity and the strong presence of traditional knowledge among local communities (Martin, 2007). Information regarding ethnobotanical and medicinal plant uses was collected from local inhabitants, who possess extensive knowledge of plant-based remedies used for the treatment of various diseases in the region (Martin, 1995). Their contributions were essential in documenting traditional practices and plant utilization patterns in the District Dir Lower (Marwat *et al*., 2012).

Collection

An ethnobotanical survey was carried out during the summer of 2017 in the study area. Field visits were conducted to collect plant specimens (Matthews and Medhi, 2014). Depending on the species, either whole plants (including roots and rhizomes) or specific plant parts such as roots, stems, and leaves were collected for further study (Mesfin *et al*., 2014). Ethnobotanical information was gathered from local inhabitants through structured questionnaires and interviews conducted during the field visits (Mohamadi *et al*., 2015). Interviews were carried out on a one-to-one basis, primarily with elderly individuals who possessed extensive knowledge of the traditional uses of indigenous plants (Mesfin *et al*., 2013). Their insights were valuable in documenting the ethnomedicinal practices of the region.

Identification and preservation of plant specimens

Plant specimens were identified using available literature, standard botanical references, and online databases (Mohammadi *et al*., 2016). Following standard herbarium procedures, collected specimens were properly pressed, dried, and preserved. The identification process included recording the scientific names along with their respective genera, families, and authorities. Additional information, such as local names, collection locality, collectors' names, and the identifier's name, was also documented (Mosaddegh *et al*., 2016). Ethnobotanical details, including the parts of the plant used and their medicinal or local applications, were carefully noted and labeled with each specimen (Murray, 2013). The preserved plant specimens were mounted on standard herbarium sheets (40 × 25 cm) and deposited in the Herbarium of Government Post Graduate College, Timergara, Dir Lower, Pakistan. To protect the specimens from fungal attack, they were stored in paper treated with antifungal agents such as naphthalene (Naz *et al*., 2014). The drying papers were replaced every two days to ensure proper preservation and prevent deterioration. Plant identification was further confirmed using standard floras (e.g., Ali & Qaiser, Flora of Pakistan) (Negbenebor *et al*., 2017).

Data analysis

The collected ethnobotanical data were analyzed using both descriptive statistics and standard quantitative ethnobotanical indices. Descriptive analysis was used to summarize plant diversity, growth forms, seasonal availability, and utilization categories. To evaluate the relative importance and consensus of medicinal plant use, the quantitative indices were applied.

Data visualization

Graphical representations of the data, including bar plots, were prepared using R software version 3.4 to present plant use categories, medicinal applications, family composition, and growth-form distribution.

Results

Floristic composition

The floristic diversity of the study area comprised 50 plant species belonging to 48 genera and 34 families. Among these, Rosaceae was the dominant family, contributing 6 species (12%), followed by Papilionaceae with 4 species (8%). Poaceae and Moraceae were each represented by 3 species (6%), while Apiaceae, Rhamnaceae, Fagaceae, and Ebenaceae each contributed 2 species (4%). The remaining 28 families were represented by a single species each (2%). In terms of morphological characteristics, the majority of plant species were non-spiny, accounting for 46 species (92%), whereas only 4 species (8%) were spiny. Regarding growth forms, herbs were the most dominant life form in the study area, comprising 38 species (55.88%), followed by trees and shrubs, each represented by 15 species (22.05%), Table 1 and Table 2. These findings are consistent with previous studies, where Rosaceae and Papilionaceae were reported as dominant families in similar ecological regions (Oliveira *et al*., 2009). Comparable results have also been documented by Khan *et al*. (2025), Ullah (2025), as well as in the Flora of Pakistan (Ali and Qaisar, 1995–2009).

Seasonal variation of plant species

The seasonal distribution of plant species in the study

Table 1: *Floristic list of khall dowab dir lower*

Botanical name	Local name	Family name	A	W	SP	SM	Habitat	Habit	Spinaceous
Agaricus campestris L	Kharerhay	Agaricaceae	_	_	+	+	W	H	_
Artemisia scoparaia. Waldst & Kitam	Jawkay	Asteraceae	_	_	+	+	D	H	_
Cotoneaster microphyllus Wall. Ex Lindley.	Mamanrha	Rosaceae	+	+	+	+	D	SB	+
Chenopodium album L	Sarmay	Chenopodiaceae	_	_	+	+	D	H	_
Celtis australis	Tagha	Ulmaceae	+	+	+	+	D	T	_
Caralluma tuberculata N.E. Brown	Pamankay	Asclepiadaceae	+	+	+	+	D	H	_
Cynodon dactylon (L.) Pers	Kabal	Poaceae	+	+	+	+	D&W	H	_
Diospyrus kaki L	Sur Amlok	Ebenaceae	+	+	+	+	D	T	_
Diospyrus lotus L	Tor Amlok	Ebenaceae	+	+	+	+		T	_
Ficus palmata Forssk	Inzar	Moraceae	+	+	+	+	D	T	_
Ipomoea purpurea (Linn.) Roth	Prewata	Convolvulaceae	_	_	+	+	D&W	H	_
Juglan regia Linn	Ghuz	Juglandaceae	+	+	+	+	D	T	_
Morus alba L	Spen Thooth	Moraceae	+	+	+	+	D	T	_
Morus nigra L	Tor thooth	Moraceae	+	+	+	+	D	T	_
Melia azedarach	Tora shandi	Meliaceae	+	+	+	+	D	T	_
Nasturtium officinale R. Br	Tarmera	Brassicaceae	+	_	+	+	W	H	_
Narcissus poeticus L	Gule Nargas	Amaryllidaceae	_	_	+	+	D	H	_
Pyrus communis L	Nashpatai	Rosaceae	+	+	+	+	D	T	_
Populus nigra L	Sperdar	Salicaceae	+	+	+	+	W&D	T	_
Portulaca quadrifida L	Zangali Warkhrhay	Portulacaceae	_	_	_	+	D	H	+
Rumex dentatus. L	Shalkhay	Polygonaceae	_	_	+	+	D	H	_
Rubus fruticosus Agg	Karwarha	Rosaceae	_	+	+	+	D	H	_
Robinia pseudoacacia L	Kikar	Papilionaceae	+	+	+	+	D	T	+
Silene conidia L	Mangotey	Caryophyllaceae	_	_	_	+	D	H	_
Sorghum halepense Pers	Dadam	Poaceae	_	+	+	+	D	H	_
Trifolium repens L	Shautal	Papilionaceae	+	_	+	+	D	H	_
Trachyspermum ammi L	Spairkai	Apiaceae	_	_	+	+	D	H	_
Zizyphus oxyphylla Edgew	Elanai	Rhamnaceae	+	+	+	+	D	SB	+
Coriandrum sativum L	Dhanya	Apiaceae	+	_	+	+	D	H	_
Eriobotrya japonica (Thunb) Lindle.	Lokat	Rosaceae	+	+	+	+	D	T	_
Indigofera gerardiana Wall ex Baker.	Ghoreja	Papilionaceae	+	+	+	+	D	SB	_
Grewia optiva Drum. ex Burret.	Pastawony	Tiliaceae	+	+	+	+	D	T	_
Myrtus communis L.	Manu	Myrtaceae	+	+	+	+	D	SB	_
Quercus incana Lindl	Banja Seray	Fagaceae	+	+	+	+	D	T	+
Saccharum bengalense L	Sharghas hy	Poaceae	+	+	+	+	D	H	_
Vicia sativa L..	Merghay khpa	Papilionaceae	_	_	+	+	D	H	_
Ailanthus altissima (Mill) Swingle	Khara Shandai	Simaroubaceae	+	+	+	+	D	T	_
Cedrus dudara (Roxb. ex Lamb.) G. Don	Deyaar	Pinaceae	+	+	+	+	D	T	_
Malva neglecta Wall	Panirak	Malvaceae	+	+	_	_	W&D	H	_
Medicago denticulate	Shpastary	Fabaceae	_	_	+	+	D	H	_

Quercus baloot Griffith	Zagavan/ Sarai	Fagaceae	+	+	+	+	D	T	+
Isodon rugosus	karachay	Labiatae	+	+	_	_	D	H	_
Brassica campestris Linn.	Sharsham	Brassicaeae	_	_	+	+	D	H	_
Cana indica Linn	Kela Botay	Cannaceae	+	_	+	+	W&D	H	_
Morus lavaegata Wallich. Ex Brandis.	Shahthooth	Moraceae	+	+	+	+	D	T	_
Oxalis corniculata L	gulday Tarokai	Oxalidaceae	+	_	+	+	D	H	_
Pyrus pashia Buch-ham ex. Don	Tangga	Rosaceae	+	+	+	+	D	T	_
Rosa webbiana Wallich ex Royle	Zangali Gulap	Rosaceae	+	+	+	+	D	SB	+
Stelaria media (L.) Vill	Wargastalay	Carophyllaceae	_	_	+	+	W	H	_
Ziziphus sativa Gaert	Markhany	Rhamnaceae	+	+	+	+	D	T	+

Key words: *Seasonal Availability: Autumn=A, Winter=W, Summer=SM, Spring=SP, Habitat: Dry=D. Wet=W, Habit: =H. Shrub=Sb. Trees=T*

area showed marked variation (Figure 1). A total of 48 species (96%) were recorded during the spring season, representing the highest level of species availability. This was followed by summer, with 42 species (84%), indicating continued favorable growth conditions. In contrast, species richness declined during autumn and winter, with 32 species (64%) and 31 species (64%), respectively. The high diversity observed in spring may be attributed to optimal climatic conditions, including moderate temperature and adequate moisture, which promote plant growth and regeneration. Conversely, the reduced number of species in autumn and winter reflects the impact of seasonal stress, including lower temperatures and limited growth activity (Manan *et al.*, 2025). Overall, these results demonstrate a clear seasonal pattern in plant availability, with peak diversity occurring in spring Table 1 and Table 2.

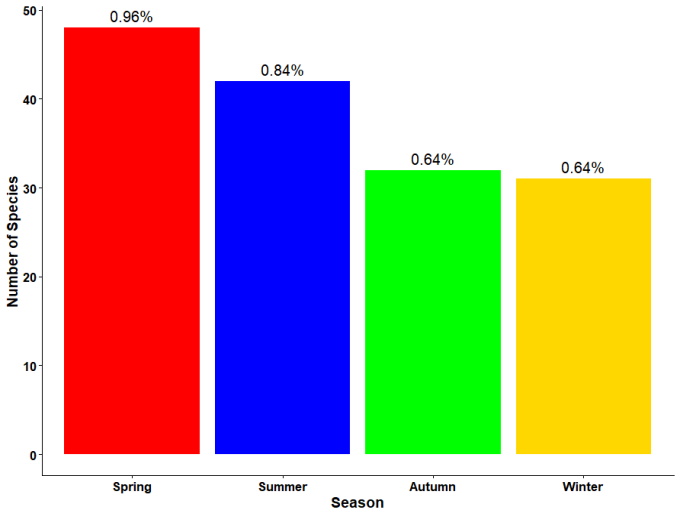

Figure 1: *Seasonal distribution of plant species in the study area, indicating higher species richness in spring and comparatively reduced availability during autumn and winter.*

Family-wise distribution of plant species

The distribution of plant species among different families showed clear variation in dominance within the study area (Figure 2). Rosaceae was the most dominant family, contributing 12% of the total species, followed by Papilionaceae with 8%. Poaceae and Moraceae were equally represented, each accounting for 6% of the recorded species. Several other families, including Apiaceae, Rhamnaceae, Fagaceae, and Ebenaceae, showed moderate representation, each contributing 4%. In contrast, a large number of families were represented by a single species, each accounting for a small proportion of the total flora, indicating high taxonomic diversity (Ullah *et al.*, 2025). The dominance of Rosaceae and Papilionaceae suggests their strong ecological adaptability to the environmental conditions of the study area, while the presence of numerous less-represented families reflects the overall richness and heterogeneity of the local flora Table 1 and Table 2.

Spiny vs non-spiny species

The classification of plant species based on spine characteristics revealed a clear dominance of non-spiny species in the study area (Figure 3). Non-spiny plants constituted the majority, accounting for 92% of the total recorded species, whereas spiny species represented only 8%. This pattern indicates that the vegetation of the study area is largely composed of non-spiny taxa, which may be associated with the prevailing environmental conditions and ecological adaptations (Khan *et al.*, 2024). The relatively lower proportion of spiny species suggests limited adaptation to arid or grazing-pressure conditions, where spines are typically more common as protective structures

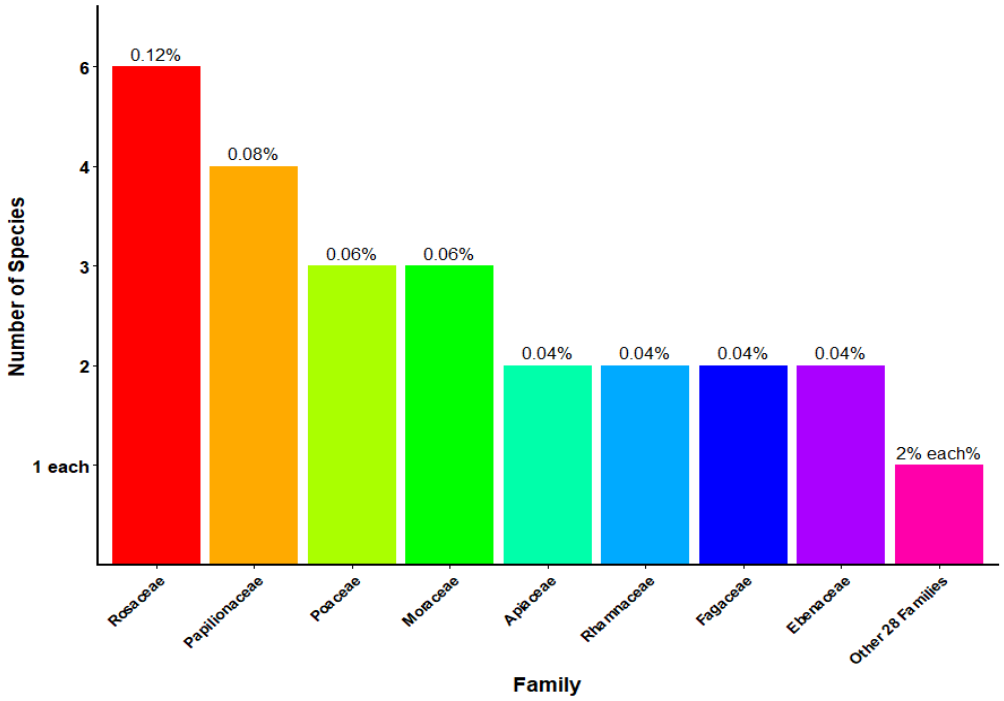

Figure 2: *Family-wise composition of plant species recorded in the study area, highlighting the predominance of Rosaceae and Papilionaceae, with other families showing relatively lower representation.*

Table 1 and Table 2.

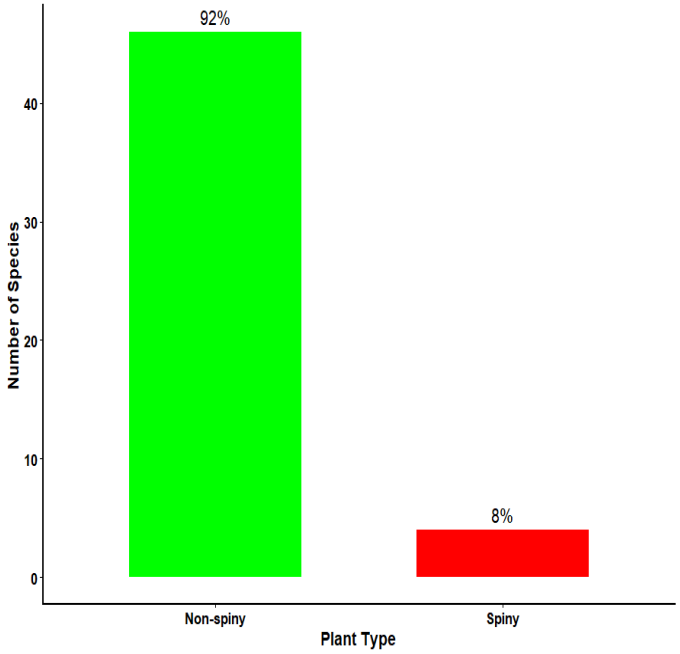

Figure 3: *Distribution of plant species based on spine characteristics in the study area, showing a clear dominance of non-spiny species compared to spiny species.*

Growth form distribution

The analysis of growth forms revealed a clear dominance of herbs in the study area (Figure 4). Herbs constituted the majority of the recorded species, accounting for 55.88% of the total flora. In contrast, trees and shrubs were equally represented, each contributing 22.05%. The predominance of herbaceous species reflects the ecological characteristics of the region, where favorable seasonal conditions and open habitats support the growth of short-lived and fast-growing plant forms. The relatively equal representation of trees and shrubs indicates a balanced presence of woody vegetation, contributing to the structural diversity of the ecosystem (Ullah, 2024).

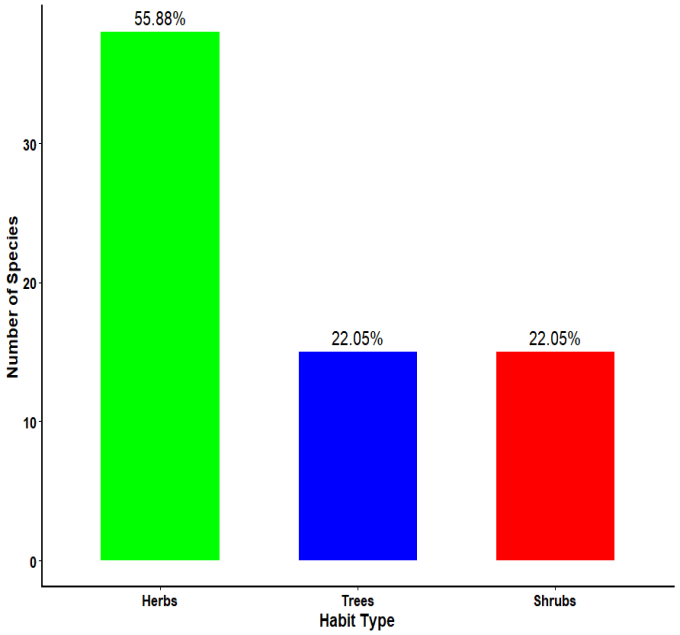

Figure 4: *Distribution of plant species based on growth forms in the study area, showing the dominance of herbs, followed by trees and shrubs.*

Table 2: *Ethnomedicinal plants of khall dowab dir lower*

S. N0	Botanical name	Local name	Family name	Habit	Parts used	Ethnomedicinal
1	*Acacia nilotica* (L.) Delile	Kikar	Mimosaceae	Tree	Flower	Flowers: Combined with sugar, they are used as a remedy for cough.
2	*Acacia modesta* Wall	Palosa	Mimosaceae	Tree	Gum and wood	Gum: Acts as a tonic and is also taken for cough relief.
3	*Berberis lyceum* Royle	Kwaray	Berberidaceae	Shrub	Root, bark, and fruit	Root bark: Used in the treatment of hepatitis, throat infections, asthma, cholera, and constipation. It is also taken with water for blood purification.
4	*Chenopodium batrys* L.	Kharawa	Chenopodiaceae	Herb	Whole plant	Practical uses: Parts of the plant are used for washing utensils, as a source of fuel, a cooling agent, and for managing infections.
5	*Caralluma tuberculata* N.E. Brown	Pamankay	Asclepiadaceae	Herb	Whole plant	Juice: Taken to help manage diabetes.
6	*Cannabis sativa* Linn	Bhang	Cannabaceae	Herb	Whole plant	Leaf juice: Used in treating malaria, relieving pain, and easing flatulence and colic pain.
7	*Calotropis procera* (Wild) R. Brown	Spalmai	Asclepiadaceae	Herb	Whole plant	Female plant: Traditionally used in making hashish (chars).
8	*Duchesnea indica* (Andr) Folke.	Da Zmake thooth	Rosaceae	Herb	Whole plant	Leaf paste (in oil): Applied as a natural painkiller and to treat skin conditions such as itching and scabies.
9	*Dodonea viscosa* (L.) Jacq	Ghwarhaskay	Sapindaceae	Shrub	Whole plant	Fruit: Considered a tonic and a cooling agent.
10	*Daphne macronata* Royle	Lighonay	Thymeleaceae	Shrub	Whole plant	Fruit juice: Used for treating eye infections.
11	*Euphorbia heliscopia* Linn	Mandanrho	Euphorbiaceae	Herb	Whole plant	Ash: Applied to burns and skin infections.
12	*Equisitum arvense* L	Bandakay	Equisetaceae	Herb	Whole plant	Used for inflammation of the urinary bladder and other urinary problems. Also used as fodder and as a fuel.
13	*Foeniculum vulgare* Mill	Kagay elanay	Apiaceae	Herb	Whole plant	Fruit is used as a carminative, to control vomiting, and as a flavoring agent.
14	*Mentha longifolia* (Linn) Huds.	Elannay	Lamiaceae	Herb	Whole plant	Leaves are used to reduce stomach problems, relieve gastric acidity, act as a carminative, and ease abdominal pain.
15	*Mentha arvensis* L	Phodena	Lamiaceae	Herb	Whole plant	Leaves are used to relieve stomach problems like diarrhea, gastric acidity, and carminative, and to relieve abdominal pain.
16	Melia azedarach	Tora shandi	Meliaceae	Tree	Wood and leaves	Leaves are used as an antidandruff agent.
17	*Olea ferrginea* Royle	Khona	Oleaceae	Tree	Fruit and wood	Olive oil is used for joint pain. Leaves are used in diabetes.
18	*Ocimum basilicum* L	Kashmalay	Lamiaceae	Herb	Whole plant	Leaves are used for cough and flu.
19	Punica granatum	Anangori	Punicaceae	Tree	Bark and wood	Fruit is edible. Ash of fruit rind is used in hepatitis, digestive problems, and bark of the fruit is used in urinary problems.
20	*Platanus orientalis* L	Chinar	Platanaceae	Tree	Whole plant	Leaves are used in dysentery.
21	*Pinus roxburghii* Sargent	Nakhtar	Pinaceae	Tree	Gum, seed, and wood	Resin is used for skin disease.

22	*Rumex hastatus* D.Don	Tarokay	Polygonaceae	Herb	Leaves	Leaves are used as a carminative, diuretic, and in jaundice. Leaves are cooked as a vegetable and also eaten uncooked. Leaf juice is used for blood clotting during injuries.
23	*Salix acmophylla* L	Walla	Salicaceae	Tree	Bark and wood	Leaves are used externally to relieve pain.
24	*Ricinus communis* L	Arhanda	Euphorbiaceae	Tree	Seed	Seed used for swellings and to treat constipation. Local Hakeems use it as an antidote for arsenic poisoning. Seeds are used for cough, fever, and headache.
25	*Rabdosia rugosa* (Wallich ex. Benth) Hara	Spaerkay	Lamiaceae	Herb	Leaves	Leaves are used for colic. Leaf extract is also used as a vermicide and insecticide.
26	*Salvia moorcroftiana* Wall. Ex Benth.	Khar ghwag	Lamiaceae	Herb	Leaves	Leaves are commonly used to relieve pain. And also used for the treatment of swelling.
27	*Tribulus terrestris* L	Markundai	Zygophyllaceae	Herb	Seed	Seeds are used as a general tonic, used in urinary disorders and impotency. And fruits are used for nostrils relaxation during flu.
28	*Trachyspermum ammi* L	Spairkai	Apiaceae	Herb	Whole plant	Fruit is used as a carminative, digestive, and for colic pain
29	*Urtica dioica* Linn	Sezonkay	Urticaceae	Herb	Whole plant	The whole plant is used as a diuretic, also used in jaundice.
30	*Verbascum Thapsus* L	Khardag	Scrophulariaceae	Herb	Leaves	Leaves are used externally to relieve pain. Leaves are used in fevers, flu, and as an expectorant.
31	*Zizyhus oxyphyla* Edgew	Elanai	Rhamnaceae	Shrub	Fruit and wood	Fruit is edible. Wood is used as fuel. Root extract is used for hepatitis. Fruit is also used as a heart tonic.
32	*Zanthoxylum armatum* DC	Dambara	Rutaceae	Shrub	Fruit	Fruit is used for treating stomach disorders.
33	*Ajuga bracteosa* Wall. ex. Benth	Gotty	Lamiaceae	HERB	Leaves	Locally, leaves are used for sour of throat and also used as a carminative and body coolant. They are also used for blood purification.
34	*Coriandrum sativum* L	Dhanya	Apiaceae	HERB	Seed and leaves	Boiled seed solution is used as an antiemetic and for cough. Leaves and seeds are used as condiments, stimulants, and flavoring agents.
35	*Datura stramonium* L	Batoray	Solanaceae	HERB	Seed and leaves	Seeds are used as a narcotic, while the leaf extract is used for toothache and headache, and cough.
36	*Eriobotrya japonica* (Thunb) Lindle.	Lokat	Rosaceae	Tree	Fruit and leaves	leaves decoction is used to lower the blood glucose level (mostly by diabetes patients)
37	*Eucalyptus lanceolatus* L	Lachi	Myrtaceae	Tree	Seed and wood	The powdered seeds are used to suppress cough.
38	*Grewia optiva* Drum. Ex Burret.	Pastawony	Tiliaceae	Tree	Bark and leaves	Boiled bark decoction is used as an antipyretic. It is also used to treat Charmaikh (Pashto name of an ailment).
39	*Morchella esculenta* L.	Khosay	Helvelaceae	mashroom	Whole body	Used as a body tonic and nutritive food, and also edible. And used in different types of medicine.

40	*Periploca aphylla* Decne	Barara	Asclepiadaceae	Shrub	Whole	Stem's latex is used to remove dermal tumors, while the whole plant decoction is purgative. Also used for cough
41	Pinus roxburghii Sargent	Nakhtar	Pinaceae	Tree	Gum, seed and wood	The resin is used externally for the removal of spots and warts. Leaf extract is used against scorpion bites.
42	*Ricinus communis* L.	Herhanda	Euphorbiaceae	Shrub	Seed and leaves	Seeds are used for stomachaches and in bowel problems. Seed oil is specifically used therapeutically for constipation. Leaves are emetic, narcotic.
43	*Solanum nigrum* L.	Karmacho	Solanaceae	Herb	Whole plant	Used in diabetes, diarrhea, hypertension, stomach problems, flatulence, kidney stones, and sudden body swelling.
44	*Papaver somniferum* L	Apium or Opium	Papaveraceae	Shrub	Leaves and fruit	The capsule is cut with a blade and removed charse"" farm them. Relieve pain, Hypnotic, Sedative, Headache, Diarrhea, and Dysentery. Seeds are nutritious and also used for cough.
45	*Viola canscens* Wall. ex Roxb	Benafsha	Violaceae	Herb	Whole plant	Plants were used for cold, cough, asthma, headache, and leaves are also mixed in tea and used against chest disease.
46	Medicago denticulate	Shpastary	Fabaceae	Herb	Whole plant	. But it is also recommended in the treatment of diabetes, bladder diseases, and anemia.
47	Isodon rugosus	Da ghara karachay	Labiatae	Herb	Whole plant	Used for blood clotting. Fungal infection is removed from the mouth and used as a stimulant.
48	*Brassica campestris* Linn.	Sharrsham	Brassicaceae	Herb	Whole plant	It provides a high number of vitamins and other nutrients, which are anticancer. It helps to induce hypothyroidism and goiter. It has antiviral, antibacterial properties.
49	*Adiantum capillus-veneris* L	Sumbal	Adiantaceae	Herb	Leaves	Leaf decoction, used for cough and fever. And also used for fodder.
50	*Avena sativa* L	Jawdar	Poaceae	Herb	Whole plant	Spikes are used as a nerve tonic, laxative, and antiseptic.
51	*Artemisia absinthium* L	zangali Tarkha	Asteraceae	Herb	Whole plant	Shots are used for typhoid. Also used for conceiving pregnancy.
52	*Chenopodium ambrosioides* L.	Skhabotay	Chenopodiaceae	Herb	Shoot juice	Juice of the shoot is used for fever, especially for malaria fever.
53	*Euphorbia hirta* Linn	Jaghje	Euphorbiaceae	Herb	Seeds	Seeds are used as a tonic and for the treatment of diarrhea, and also used for cough
54	*Mirabilis jalapa* Linn	Mazegargulay	Nyctaginaceae	Shrub	Whole plant	Leaves are used to treat abscesses. Root tubers are used as pain painkiller and also for the treatment of typhoid.
55	*Papaver pavoninum* Schrenk	Reddai gul	Papaveraceae	Herb	Flowers	Flowers are used as a sedative
56	*Stelaria media* (L.) Vill	Wargastalay	Caryophyllaceae	Herb	Whole plant	used for constipation and fodder for animals.
57	*Cuscuta reflexa* Roxb	Mechaa	Cuscutaceae	Herb	Whole plant	Stem is used for fever and skin itching.
58	*Trifolium repens* L	Shautal	Papilionaceae	Herb	Leaves and stem	The seeds are used for the treatment of pimples.

Links Researchers

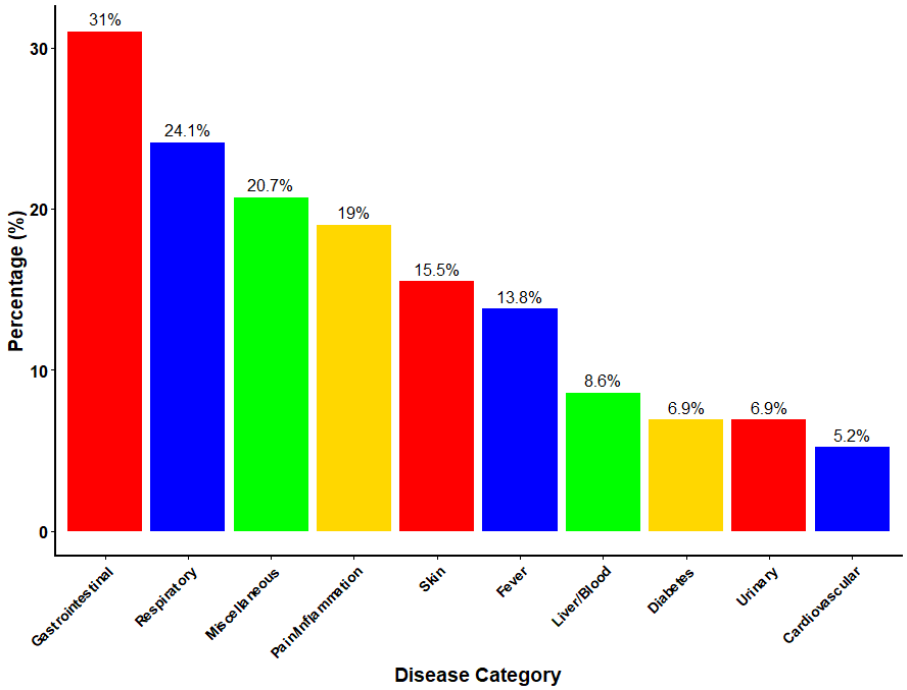

Figure 5: *Distribution of ethnomedicinal plant use across different disease categories in the study area, showing the highest usage for gastrointestinal disorders, followed by respiratory, miscellaneous, and pain/inflammation, with lower representation in other categories.*

Disease-wise medicinal plant use

The categorization of ethnomedicinal plant uses revealed significant variation across different disease groups (Figure 5). Gastrointestinal disorders represented the most treated category, accounting for 31% of the recorded uses (Subhan *et al.*, 2024). This was followed by respiratory ailments (24.1%), miscellaneous uses (20.7%), and pain and inflammation-related conditions (19%). Moderate usage was observed for skin-related diseases (15.5%) and fever (13.8%), indicating their common occurrence in the study area. In contrast, comparatively fewer plant species were used for liver and blood-related disorders (8.6%), diabetes (6.9%), urinary problems (6.9%), and cardiovascular diseases (5.2%) (Ullah *et al.*, 2024). The dominance of gastrointestinal and respiratory treatments highlights the prevalence of these health issues in the local community, as well as the reliance on traditional plant-based remedies for their management Table 7, Table 8, and Table 9.

Taxonomic composition

The taxonomic analysis of the recorded flora revealed considerable diversity within the study area (Figure 6). A total of 58 plant species were documented, belonging to 54 genera and 36 families (Ullah *et al.*, 2024). The close correspondence between the number of species and genera indicates a high level of taxonomic diversity, with most genera represented by a single species (Ullah *et al.*, 2023). The relatively large number of families further reflects the heterogeneity and richness of the flora in the region. This pattern suggests that the study area supports a wide range of plant taxa with limited dominance of individual genera, highlighting its ecological diversity and importance for biodiversity conservation Table 6 and Table 7.

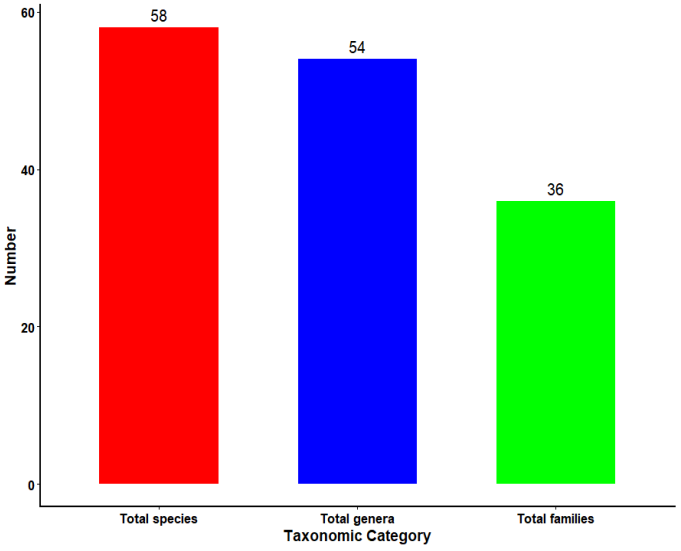

Figure 6: *Taxonomic composition of the recorded flora in the study area, showing the total number of species, genera, and families documented.*

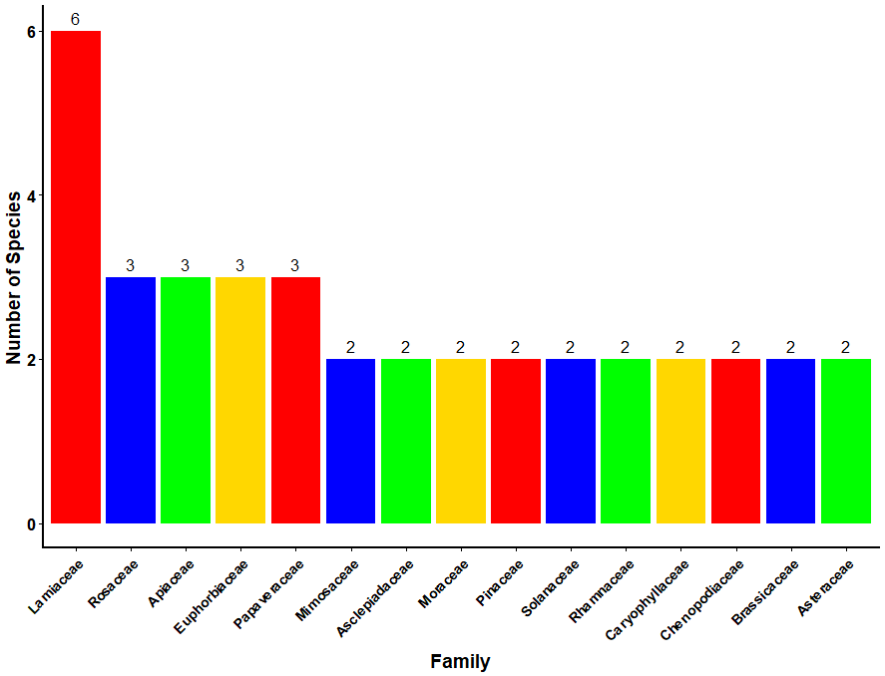

Figure 7: *Distribution of ethnomedicinal plant species among different families in the study area, highlighting the dominance of Lamiaceae, followed by several moderately represented families.*

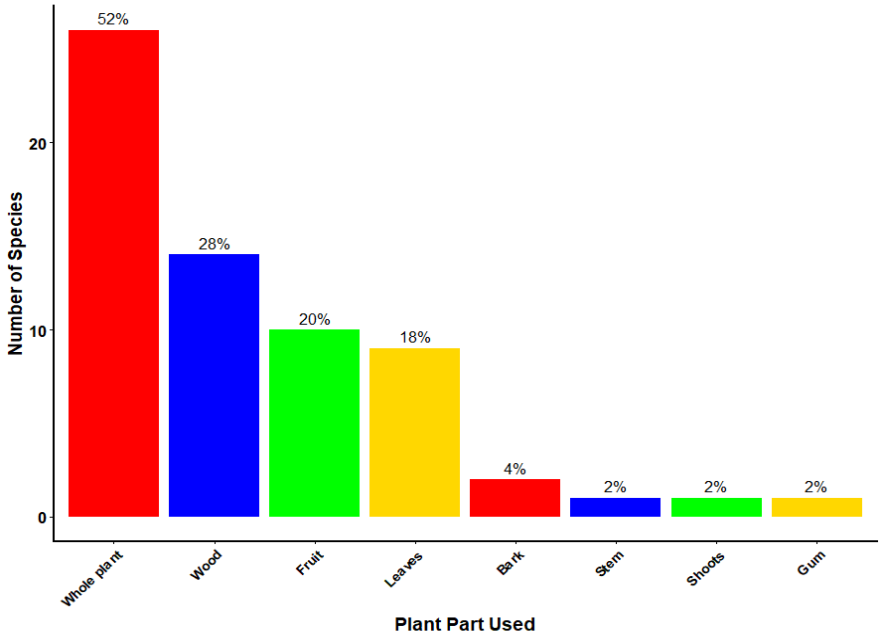

Figure 8: *Percentage distribution of plant parts used in ethnomedicinal practices in the study area, showing the highest utilization of whole plants, followed by wood, fruits, and leaves, while other parts were used less frequently.*

Ethnomedicinal family distribution

The distribution of ethnomedicinal plant species among families showed noticeable variation in representation (Figure 7). Lamiaceae was the most dominant family, contributing the highest number of species. Several other families, including Rosaceae, Apiaceae, Euphorbiaceae, and Papaveraceae, showed moderate representation. In contrast, several families, such as Mimosaceae, Asclepiadaceae, Moraceae, Pinaceae, Solanaceae, Rhamnaceae, Caryophyllaceae, Chenopodiaceae, Brassicaceae, and Asteraceae, were represented by comparatively fewer species (Ullah *et al.*, 2023). This distribution pattern reflects the prominence of certain families, particularly Lamiaceae, in traditional medicinal practices, likely due to their rich phytochemical composition and well-known therapeutic properties. At the same time, the presence of many less-represented families indicates a broad ethnomedicinal base and highlights the diversity of plant resources utilized by local communities Table 5

and Table 6, and Table 10, Sajid *et al.*, 2023).

Table 3: *Medicinal plants used for cough*

S.NO	Botanical name	Local name	Family name
1	*Acacia nilotica* (L.) Delile	Kikar	Mimosaceae
2	*Acacia modesta* Wall	Palosa	Mimosaceae
3	*Datura stramonium* L	Batoray	Solanaceae
4	*Papaver somniferum* L	Apium or Opium	Papaveraceae
5	*Viola canscens* Wall. ex Roxb	Benafsha	Violaceae
6	*Euphorbia hirta* Linn	Jaghje	Euphorbiaceae
7	*Eucalyptus lanceolatus* L	Lachi	Myrtaceae
8	*Coriandrum sativum* L	Dhanya	Apiaceae
9	Periploca aphylla Decne	Barara	Asclepiadaceae
10	*Adiantum capillus-veneris* L	Sumbal	Adiantaceae
11	*Datura stramonium* L	Batoray	Solanaceae

Table 4: *Medicinal plants used as anthelminthic*

S.No	Botanical name	Local name	Family name
1	*Acacia nilotica* (L.) Delile	Kikar	Mimosaceae
2	*Dodonea viscosa* (L.) Jacq	Ghwarhaskay	Sapindaceae
3	*Papaver pavoninum* Schrenk	Reddai gul	Papveraceae
4	*Ricinus communis* L.	Herhanda	Euphorbiaceae
5	*Mirabilis jalapa* Linn	Mazegargulay	Nyctaginaceae
6	*Ricinus communis* L.	Herhanda	Euphorbiaceae

Table 5: *Medicinal plants used as diuretics*

S.No	Botanical name	Local Name	Family name
1	*Grewia optiva Drum.* Ex Burret.	Pastawony	Tiliaceae
2	*Solanum nigrum* L.	Karmacho	Solanaceae
3	*Tribulus terrestris* L	Markun-dai	Zygophyllaceae
4	Periploca aphylla Decne	Barara	Asclepiadaceae
5	*Ricinus communis* L.	Herhanda	Euphorbiaceae

Plant parts used

The analysis of plant parts used in ethnomedicinal practices revealed considerable variation among different categories (Figure 8). The whole plant was the most frequently utilized component, accounting for 52% of the total usage. This was followed by wood (28%), fruits (20%), and leaves (18%), indicating a preference for readily available and versatile plant parts. In contrast, bark was used to a lesser extent (4%), while stems, shoots, and gum were the least utilized parts, each contributing only 2% (Ullah *et al.*, 2021). The predominance of whole plant usage reflects the traditional approach of utilizing complete plant material for medicinal preparations, whereas the use of specific parts, such as fruits and leaves, highlights their importance in targeted therapeutic applications Table 3, Table 4, and Table 11.

Table 6: *Medicinal plants used as carminative*

S. No	Botanical name	Local name	Family name
1	*Solanum nigrum* L.	Karmacho	Solanaceae
2	*Rumex hastatus* D. Don	Tarokay	Polygonaceae
3	*Ziziphus oxyphylla* Edgew	Elanai	Rhamnaceae
4	*Mentha arvensis* L	Phodena	Lamiaceae
5	*Mentha longifolia* (Linn) Huds.	Elannay	Lamiaceae

Table 7: *Medicinal plants used against inflammation*

S.No	Botanical name	Local name	Family name
1	*Mentha longifolia* (Linn) Huds.	Elannay	Lamiaceae
2	*Rumex hastatus* D.Don	Tarokay	Polygonaceae
3	*Grewia optiva Drum.* Ex Burret.	Pastawony	Tiliaceae
4	*Ricinus communis* L.	Herhanda	Euphorbiaceae

Table 8: *Medicinal plants used against diarrhea*

S.No	Botanical name	Local name	Family name
1	*Mentha longifolia* (Linn) Huds.	Elannay	Lamiaceae
2	*Mentha arvensis* L	Phodena	Lamiaceae
3	*Euphorbia hirta* Linn	Jaghje	Euphorbiaceae
4	*Papaver somniferum* L	Apium or opium	Papaveraceae

Plant use categories

The analysis of plant use categories revealed a diverse range of applications within the study area (Figure 9). Fuel was the most dominant use category, accounting for 24% of the total plant utilization. This was followed by the use of plants as vegetables (22%)

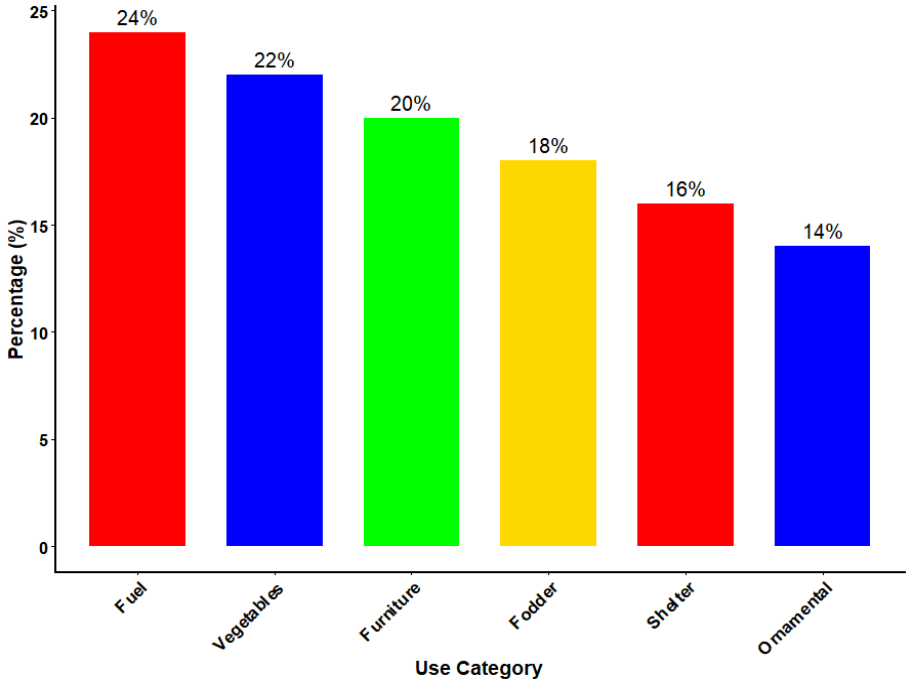

Figure 9: *Percentage distribution of plant use categories in the study area, showing the highest utilization for fuel, followed by vegetables, furniture, fodder, shelter, and ornamental purposes.*

and for furniture (20%), indicating their importance in meeting daily subsistence and household needs. Fodder use was also significant, contributing 18%, reflecting the reliance of local communities on plant resources for livestock feeding (Ullah *et al.*, 2021). In contrast, plants used for shelter (16%) and ornamental purposes (14%) were comparatively less represented. The predominance of fuel and food-related uses highlights the dependence of local populations on plant resources for basic energy and nutritional requirements, emphasizing the critical role of plant biodiversity in sustaining rural livelihoods Table 12, Table 13, Table 14, Table 15, and Table 16.

Table 9: *Medicinal plants used against asthma*

S.No	Botanical name	Local name	Family name
1	*Datura stramonium* L	Batoray	Solanaceae
2	*Berberis lyceum* Royle	Kwaray	Berberidaceae
3	*Adiantum capil-lus-veneris* L	Sumbal	Adiantaceae
4	*Ocimum basilicum* L	Kashmalay	Lamiaceae

Relative value analysis – RVA

The Relative Value Analysis (RVA) of plant species revealed a clear dominance of medium-value (MV) species in the study area (Figure 10). MV species constituted the majority, accounting for 88.9% of the recorded plants, indicating their widespread use and moderate importance in local ethnobotanical practices (Ullah, 2017). In contrast, high-value (HV) species represented only 11.1%, reflecting a smaller proportion of highly preferred or specialized medicinal plants (Ullah *et al.*, 2019). The predominance of MV species suggests that local communities rely more on commonly available and multipurpose plant species, while HV species are comparatively limited, possibly due to their specific uses, restricted availability, or higher cultural significance Table 17.

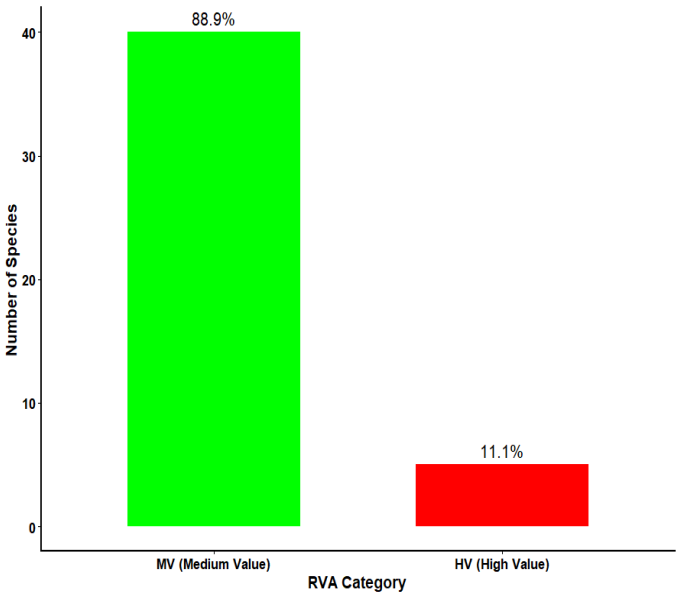

Figure 10: *Distribution of plant species across Relative Value Analysis (RVA) categories in the study area, showing a strong dominance of medium-value (MV) species compared to high-value (HV) species.*

Table 10: *Ethnobotanical plants of khall dowab, dir lower*

S. No	Botanical name	Local name	Family name	Habit	Part used	Ethno botanical uses
1	*Agaricus campestris* L	Kharerhay	Agaricaceae	Mush-room	Whole plant	Cooked as food.
2	*Artemisia scoparaia.* Waldst & Kitam	Jawkay	Asteraceae	Herb	whole plant	The plant is also used as fuel and for sweeping.
3	*Cotoneaster microphyllus* Wall. Ex Lindley.	Mamanrha	Rosaceae	Tree	Whole plant	Fruit is edible. Wood is used as fuel.
4	*Chenopodium album* L	Sarmay	Chenopodiaceae	Herb	Whole plant	Leaves and young shoots are cooked as a vegetable. and also used for the fodder.
5	Celtis australis	Tagha	Ulmaceae	Tree	Leaves and wood	Fruit is edible. Wood is used in furniture, for timber, and as fuel, and leaves are also used for fodder.
6	*Caralluma tuberculata* N.E. Brown	Pamankay	Asclepiadaceae	Herb	Whole plant	Herb Cooked as a vegetable.
7	*Cynodon dactylon* (L.) Pers	Kabal	Poaceae	Herb	Whole plant	Grown in lawns for the ornaments, and also used as fodder for grazing cattle.
8	*Diospyrus kaki* L	Sur Amlok	Ebenaceae	Tree	Fruit and wood	Fruit is edible and also a source of income for the locals, sold locally and in other parts of the country. Leaves are used as fodder for cattle. Wood is used for fuel and timber.
9	*Diospyrus lotus* L	Tor Amlok	Ebenaceae	Tree	Fruit and wood	Leaves are used as fodder for goat and sheep. Wood is used as fuel. And fruits are also edible
10	*Ficus palmata* Forssk	Inzar	Moraceae	Tree	Fruit, wood, and gum	Fruit is edible, eaten fresh as well as dried. Latex is used to extract the spine from skin and is a fuel and timber
11	*Ipomoea purpurea* (Linn.) Roth	Prewata	Convolvulaceae	Herb	Whole plant	Used as Ornamental and fodder for animals.
12	*Juglan regia* Linn	Ghuz	Juglandaceae	Tree	Fruit,wood and bark	Fruit is edible. Bark and leaves, locally used for cleaning teeth and to colour lips. Wood is used for furniture and fuel.
13	*Morus alba* L	Spen Thooth	Moraceae	Tree	Furit and wood	Fruit is edible. Leaves are used as fodder for cattle. Wood is used for making furniture, for timber, for making agricultural tools, and as a fuel.
14	*Morus nigra* L	Tor thooth	Moraceae	Tree	Fruit and wood	Fruit is edible. Wood is used in making furniture, for timber, for making agricultural tools, and as a fuel. Leaves are used as fodder for cattle
15	Melia azedarach	Tora shandi	Meliaceae	Tree	Wood and leaves	Leaves are used as fodder, and Wood is used for making furniture and also for burning.
16	*Nasturtium officinale* R. Br	Tarmera	Brassicaceae	Herb	Whole plant	Cooked as a vegetable.
17	*Narcissus poeticus* L	Gule Nargas	Amaryllidaceae	Herb	Whole plant	Flowers are used for ornamental purposes. Grown on graves and lawn.
18	*Pyrus communis* L	Nashpatai	Rosaceae	Tree	Fruit and wood	Food is edible. Fruit is a source of income, sold locally and in other parts of the country. Wood is used as fuel and timber.
19	*Populus nigra* L	Sperdar	Salicaceae	Tree	Wood and leaves	Wood is very useful and used in making furniture and timber. Branches are used as firewood. Leaves are used as fodder and the stems are used in sports tools like bats and wickets.

20	*Portulaca quadrifida* L	Zangali Warkhrhay	Portulacaceae	Herb	Whole plant	Used as a vegetable and fodder for animals.
21	*Rumex dentatus.* L	Shalkhay	Polygonaceae	Herb	Whole plant	Cooked as vegetables. Also used to treat constipation in cattle. used as fodder for animals.
22	*Rubus fruticosus* Agg	Karwarha	Rosaceae	Shrub	Whole plant	Fruit is edible. Plants are used for making a hedge. Used as fodder for animals and also as a fuel.
23	*Robinia pseduacacia* L	Kikar	Papilionaceae	Tree	Bark and wood	Wood is used as fuel. Honey bee plant. Cultivated as a roadside shade plant. and leaves are also used for fodder
24	*Silene conidia* L	Mangotey	Caryophyllaceae	Herb	Whole plant	Used as vegetables (SAAG) and fodder for cattle.
25	*Sorghum halepense* Pers	Dadam	Poaceae	Herb	Whole plant	Mature plants are used as fodder for cattle.
26	*Trifolium repens* L	Shautal	Papilionaceae	Herb	Leaves and stem	Used as fodder for cattle. The seeds are used for the treatment of pimples, and are also used as a vegetable.
27	*Trachy spermum* ammi L	Spairkai	Apiaceae	herb	Whole plant	Used in different foods
28	*Zizyhus oxyphyla* Edgew	Elanai	Rhamnaceae	tree	Whole plant	Fruit is edible. Wood is used as fuel.
29	*Coriandrum sativum* L	Dhanya	Apiaceae	HERB	Whole plant	Used as a vegetable
30	*Eriobotrya japonica* (Thunb) Lindle.	Lokat	Rosaceae	tree	Fruit and wood	Fruits are edible.
31	*Indigofera gerardiana* Wall ex Baker.	Ghoreja	Papilionaceae	shrub	Shoots	Young shoots are used for the manufacturing of baskets. Shoots are too used to make roofs in mud construction. It may serve as fodder for cattle and also be used for fuel.
32	*Grewia optiva Drum*. Ex Burret.	Pastawony	Tiliaceae	tree	Whole plant	It is also used to treat Charmaikh (Pashto name of an ailment) in cows. Leaves are fodder for cattle, and wood is used for fuel and timber.
33	*Myrtus communis* L.	Manu	Myrtaceae	shrub	Fruit and leaves	Fruits edible. Smoke of dried leaves is spiritually considered an obstacle against evil eyes and also used as a fuel.
34	*Quercus incana* Lindl	Banja Seray	Fagaceae	tree	Whole plant	Leaves are fresh fodder for cattle. The plant is heavily used for fuel purposes. It also yields agricultural tools, together with the usage in building construction and timber.
35	*Saccharum bengalense* L	Sharghas hy	Poaceae	herb	Whole plant	Used for making baskets. Young shoots are used to make brooms and are placed at the top of huts for easy drainage of rainwater. They are also used in kite making and as a fuel.
36	*Vicia sativa* L.	Merghay khpa	Papilionaceae	herb	Whole plant	Fruits are edible, while the rest of the plant is used as a vegetable and for fodder purposes.
37	*Ailanthus altissima* (Mill) Swingle	Khara Shandai	Simaroubaceae	tree	Wood and leaves	Fodder for animals, Constructions of homes, Furniture, and Fuel wood.
38	*Cedrus dudara* (Roxb. ex Lamb.) G. Don	Deyaar	Pinaceae	tree	Whole plant	Use for construction purposes, fuel wood, Timber wood, and resistant to water

39	*Malva neglecta* Wall	Panirak	Malvaceae	herb	Whole plant	Use as vegetables, Fodder for animals.
40	Medicago denticulata	Shpastary	Fabaceae	herb	Whole plant	Use as a vegetable, salad, fodder for animals, or ornamental purposes in the lawn.
41	*Quercus baloot* Griffith	Zagavan/ Sarai	Fagaceae	tree	Wood and leaves	Wood is used as fuel and timber. also used for ornament and fodder for animals. A little amount is taken off powdered with Desi ghee.
42	Isodon rugosus	Da ghara karachay	Lamiaceae	herb	Whole plant	Fodder for animals, fuel, and urgent snuff.
43	*Brassica campestris* Linn.	Sharsham	Brassicaceae	herb	Whole plant	Young leaves and flowering tops were used as a vegetable. Oil is extracted from seeds which are used in cooking, massage of body and hair, used ointment. Seed cakes locally known as "Khal" is obtained after extracting oil and are used as fodder for cattle. Use as fodder for animals.
44	*Cana indica* Linn	Kela Botay	Cannaceae	Shrub	Whole plant	Cultivated as ornamental and used for making hedges. And also used as fodder for animals.
45	*Morus lavaegata* Wallich. Ex Brandis.	Shahthooth	Moraceae	tree	Fruit and wood	Fruit is edible. Leaves are used as fodder for cattle.
46	*Oxalis corniculata* L	gulday Tarokai	Oxalidaceae	Herb	Leaves	Used as a vegetable.
47	*Pyrus pashia* Buchham ex. Don	Tangga	Rosaceae	tree	Fruit and wood	Fruit is edible. Wood is used as fuel and timber. leaves are also used as fodder for animals.
48	*Rosa webbiana* Wallich ex Royle	Zangali Gulap	Rosaceae	Shrub	Whole plant	Used for making hedges and as an ornament. and also used for fuel and fodder for animals.
49	*Stelaria media* (L.) Vill	Wargastalay	Caryophyllaceae	herb	Whole plant	Plant is cooked as vegetable. And used as a food for animals
50	*Zizyphus sativa* Gaert	Markhany	Rhamnaceae	tree	Fruit, wood and leaves	Fruit is edible. Wood is used as fuel wood. Leaves are grazed by cattle.

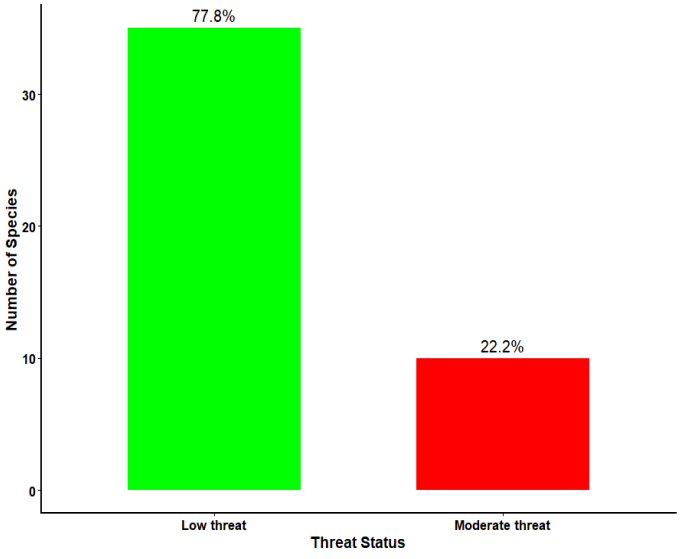

Figure 11: *Distribution of plant species based on threat status in the study area, showing the dominance of low-threat species compared to moderately threatened species.*

Threat status of plant species

The assessment of threat status revealed that the majority of plant species in the study area fall under the low-threat category (Figure 11). Low-threat species accounted for 77.8% of the total recorded flora, indicating relatively stable populations and a lower immediate risk of decline (Ullah *et al.*, 2019. In contrast, moderately threatened species represented 22.2%, suggesting that a notable proportion of plants may be experiencing pressure due to factors such as overexploitation, habitat disturbance, or environmental changes. The predominance of low-threat species reflects the resilience of the local flora; however, the presence of moderately threatened species highlights the need for conservation measures to ensure the sustainable use and long-term preservation of plant biodiversity in the region Table 17.

Table 11: *Plants used for fuel*

S. NO	Botanical name	Local name	Family name
1	*Cotoneaster microphyllus* Wall. Ex Lindley.	Mamanrha	Rosaceae
2	*Robinia pseduacacia* L	Kikar	Papilionaceae
3	*Cedrus dudara* (Roxb. ex Lamb.) G. Don	Deyaar	Pinaceae
4	*Pyrus pashia* Buch-ham ex. Don	Tangga	Rosaceae
5	Qucrcus baloot Griffith	Zagavan/ Sarai	Fagaceae
6	Pyrus pashia Buch-ham ex. Don	Tangga	Rosaceae
7	*Zizyphus sativa* Gaert	Markhany	Rhamnaceae
8	*Ailanthus altissima* (Mill) Swingle	Khara Shandai	Simaroubaceae
9	*Grewia optiva Drum.* Ex Burret.	Pastawony	Tiliaceae
10	*Saccharum bengalense* L	Sharghas hy	Poaceae
11	*Quercus incana* Lindl	Banja Seray	Fagaceae
12	*Indigofera gerardiana* Wall ex Baker.	Ghoreja	Papilionaceae
13	*Eriobotrya japonica* (Thunb) Lindle.	Lokat	Rosaceae
14	*Robinia pseduacacia* L	Kikar	Papilionaceae
15	*Populus nigra* L	Sperdar	Salicaceae
16	*Morus nigra* L	Tor thooth	Moraceae
17	*Juglan regia* Linn	Ghuz	Juglandaceae
18	*Diospyrus kaki* L	Sur Amlok	Ebenaceae
19	*Diospyrus lotus* L	Tor Amlok	Ebenaceae
20	*Ficus palmata* Forssk	Inzar	Moraceae

Table 12: *Plants used as fodder*

S.No	Botanical name	Local name	Family name
1	*Ziziphus sativa* Gaert	Markhany	Rhamnaceae
2	*Morus lavaegata* Wallich. Ex Brandis.	Shahthooth	Moraceae
3	*Grewia optiva Drum.* Ex Burret.	Pastawony	Tiliaceae
4	*Sorghum halepense* Pers	Dadam	Poaceae
5	*Brassica campestris* Linn.	Sharsham	Brassicaceae
6	*Cynodon dactylon* (L.) Pers	Kabal	Poaceae
7	*Stelaria media* (L.) Vill	Wargastalay	Caryophyllaceae
8	*Cana indica* Linn	Kela Botay	Cannaceae
9	*Trifolium repens* L	Shautal	Papilionaceae
10	Isodon rugosus	Da ghara karachay	Labiatae

Score category distribution

The classification of plant species based on score categories revealed a clear dominance of medium-score species in the study area (Figure 12). Medium-score species accounted for 55.6% of the total recorded flora, indicating their moderate importance and widespread occurrence. In contrast, both high-score and low-score categories were equally represented, each contributing 22.2% of the species (Ullah *et al.*, 2019. The predominance of medium-score species suggests that a large proportion of plants possess moderate ethnobotanical or ecological significance, while the equal distribution of high- and low-score species reflects a balanced representation of highly valuable and less-utilized plant resources within the study area Table 17.

Table 13: *Plants used for furniture*

S. NO	Botanical name	Local name	Family name
1	*Cedrus dudara* (Roxb. ex Lamb.) G. Don	Deyaar	Pinaceae
2	*Populus nigra* L	Sperdar	Salicaceae
3	*Juglan regia* Linn	Ghuz	Juglandaceae
4	*Morus nigra* L	Tor thooth	Moraceae
5	*Zizyphus sativa* Gaert	Markhany	Rhamnaceae
6	*Ailanthus altissima* (Mill) Swingle	Khara Shandai	Simaroubaceae
7	*Pyrus pashia Buch-ham* ex. Don	Tangga	Rosaceae
8	*Ficus palmata* Forssk	Inzar	Moraceae

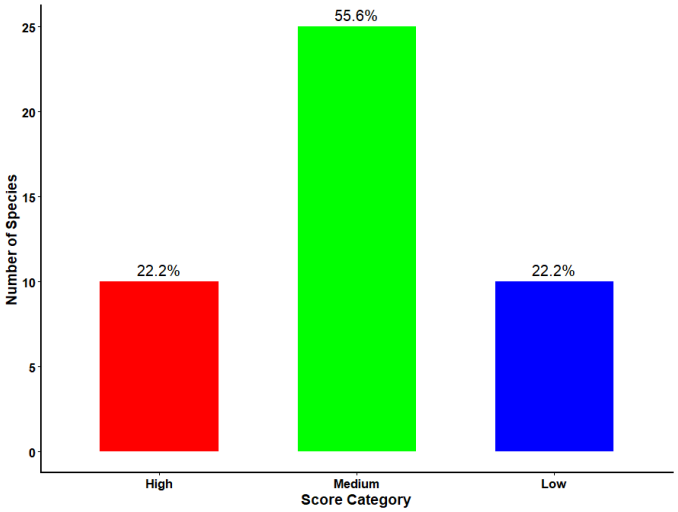

Figure 12: *Distribution of plant species across score categories in the study area, showing the dominance of medium-score species, followed by equal representation of high and low score categories.*

Species-wise total score distribution

The species-wise analysis of total scores revealed only minor variation among the selected plant species (Figure 13). *Erigeron multicaulis* and *Oxalis corniculata* recorded the highest total scores, indicating their relatively greater ethnobotanical or ecological importance in the study area. Other species, including *Dryopteris serrato-dentata*, *Indigofera heterantha*, *Parrotiopsis jacquemontiana*, *Scabiosa candollei*, and *Stipagrostis ciliata*, showed slightly lower but comparable scores. The narrow range of variation among species suggests a relatively uniform distribution of importance across the selected taxa, indicating that multiple species contribute significantly to local ethnobotanical practices rather than a single dominant species.

Correlation analysis with values

The correlation analysis revealed strong relationships among the studied ethnobotanical and ecological variables (Figure 14). Use value showed a strong positive correlation with quantity collected (r = 0.89), threat status (r = 0.92), and total score (r = 0.96), indicating that highly utilized species are more frequently collected and have greater overall importance. Similarly, total score exhibited strong positive associations with quantity collected (r = 0.97) and threat status (r = 1.00). In contrast, population size demonstrated strong negative correlations with use value (r = −0.85), quantity collected (r = −0.91), and threat status (r = −0.91), suggesting that increased utilization pressure is associated with reduced population size. Regeneration also showed strong negative correlations with use value (r = −0.87), quantity collected (r = −0.90), and threat status (r = −0.93), indicating that overexploitation may negatively affect regeneration capacity. Furthermore, regeneration exhibited a strong positive relationship with population size (r = 0.88), highlighting the interdependence between these ecological factors. Season showed weak correlations with most variables,

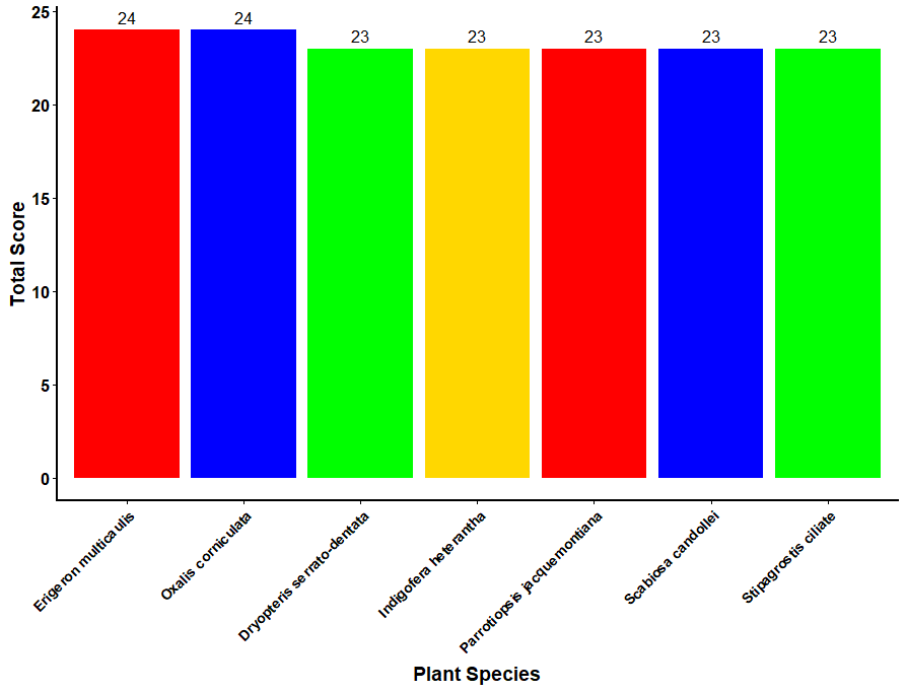

Figure 13: *Total score distribution of selected plant species in the study area, showing slight variation among species, with Erigeron multicaulis and Oxalis corniculata having the highest scores, followed closely by other species.*

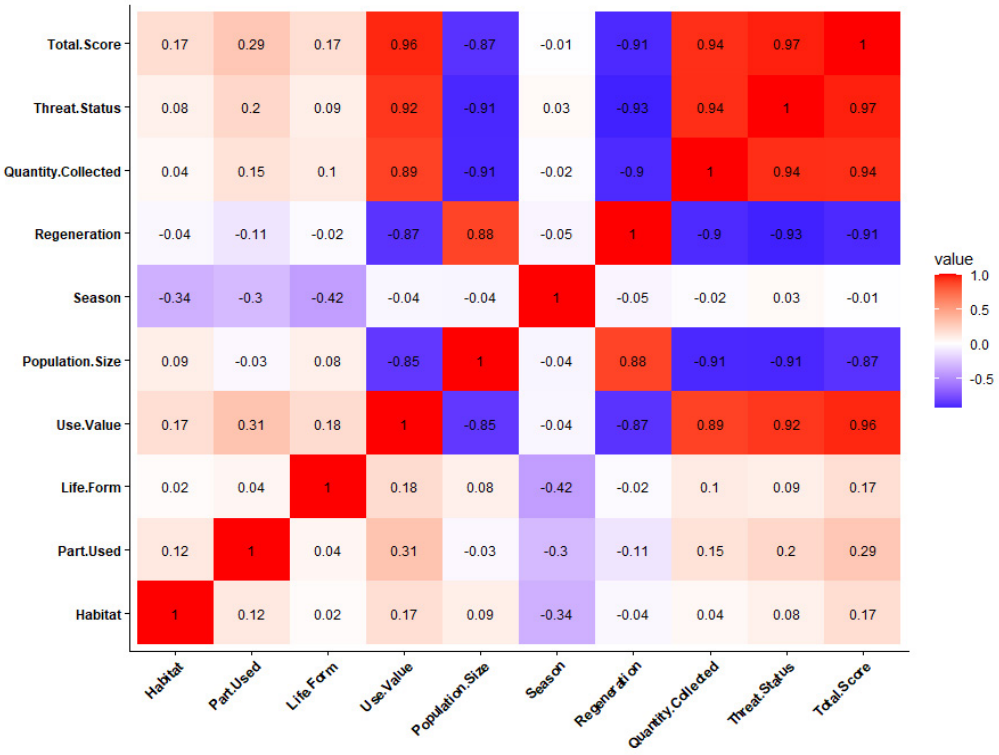

Figure 14: *Correlation matrix showing relationships among ethnobotanical and ecological variables in the study area. Positive correlations are indicated in red, while negative correlations are shown in blue, reflecting the strength and direction of associations among variables.*

ranging from r = −0.42 to 0.03, indicating minimal influence on ethnobotanical importance. Life form and plant parts used displayed generally weak to moderate correlations, suggesting a limited but variable contribution to plant utilization patterns. Overall, the correlation analysis demonstrates that use value, collection intensity, and threat status are strongly interconnected, while population size and regeneration are negatively impacted by increased utilization, emphasizing the importance of sustainable resource management.

Table 14: *Plants used as vegetables*

S.No	Botanical name	Local name	Family name
1	*Stelaria media* (L.) Vill	Wargastalay	Caryophyl-laceae
2	*Oxalis corniculata* L	gulday Tarokai	Oxalidaceae
3	*Brassica campestris* Linn.	Sharsham	Brassicaceae
4	*Vicia sativa* L.	Merghay khpa	Papilionaceae
5	Medicago denticulate	Shpastary	Fabaceae
6	*Malva neglecta* Wall	Panirak	Malvaceae
7	*Coriandrum sativum* L	Dhanya	Apiaceae
8	*Trifolium repens* L	Shautal	Papilionaceae

Table 15: *Plants used for shelter*

S.No	Botanical name	Local name	Family name
1	*Ficus palmata* Forssk	Inzar	Moraceae
2	*Quercus incana* Lindl	Banja Seray	Fagaceae

Table 16: *Plants used for ornaments*

S.No	Botanical name	Local name	Family name
1	*Narcissus poeticus* L	Gule Nargas	Amaryllidaceae
2	*Cana indica* Linn	Kela Botay	Cannaceae

Rapid vulnerability assessment parameters

The vulnerability of each species was assessed based on nine parameters:

- *Habit/Life Form* – Categorized as annual herb (1), biennial herb (2), perennial herb (3), tree (4), or shrub (5).
- *Habitat Specificity* – Ranging from highly specific (1) to occurrence in more than one ecological zone (5).
- *Parts Used* – Whole plant (1), leaf + flower + fruits (2), flower (3), stem (4), leaves (5), root (6).
- *Use Value* – Classified as multiple uses (1), three uses (2), two uses (3), or a single use (4).
- *Population Size* – Minimum (1), moderate

Table 17: *Rapid vulnerability assessment techniques*

Plant name	Habit	Habitat	Part used	Life form	Use value	Population size	Season of collection	Regenerations	Quantity collected Kg/Year	Threat status	Total score	RVA
Abies pindrow	Tree	1	1	4	3	3	1	1	1	2	17	MV
Adiantum venustum	Herb	1	2	1	4	2	1	1	5	1	18	MV
Ajuga bracteosa	Herb	2	1	3	3	4	1	1	5	1	21	MV
Ailanthus altissima	Tree	3	1	4	1	5	1	1	1	1	18	MV
Alnus nitida	Tree	1	1	4	2	2	1	1	1	1	14	HV
Aristida adscensionis	Herb	2	1	3	3	3	1	2	1	1	17	MV
Berberis lycium	Shrub	3	1	5	2	3	1	1	1	1	18	MV
Bergenia ciliata	Herb	1	1	1	3	1	1	2	4	1	15	HV
Bothriochloa ischaemum	Herb	2	1	1	3	2	1	2	1	1	14	HV
Caltha alba	Herb	1	2	3	3	1	1	1	5	1	18	MV
Cannabis sativa	Herb	3	2	1	2	2	1	1	3	1	16	MV
carotalaria calycina	Herb	2	4	1	4	3	1	1	5	2	23	MV
Cedrus deodara	Tree	3	1	4	1	5	1	1	1	2	19	MV
Cheilanthes dalhousiae	Herb	2	4	3	4	3	1	1	5	1	24	MV
Clinopodium valgure	Herb	2	2	3	4	2	1	1	5	2	22	MV
Conyza canadensis	Herb	1	2	3	4	2	1	1	5	2	21	MV
Cynodon dactylon	Herb	5	1	3	1	5	1	2	1	1	20	MV
Diospyrus lotus	Tree	4	1	4	2	5	1	1	1	1	20	MV
Dodonaea viscosa	Shrub	3	1	5	3	5	1	1	1	1	21	MV
Dryopteris serrato-dentata	Herb	2	4	2	4	2	1	1	5	2	23	MV
Echino crus galli	Herb	2	1	1	4	3	1	1	3	1	17	MV
Erigeron multicaulis	Herb	1	4	3	4	3	1	1	5	2	24	MV
Eucalyptus globulus	Tree	3	3	4	2	4	1	1	1	1	20	MV
Ficus carica	Tree	4	1	4	1	5	1	1	1	1	19	MV
Heteropogon contortus	Herb	2	1	3	3	3	1	2	1	1	17	MV
hypodematium cerenatum	Herb	1	1	3	3	3	1	1	5	2	20	MV
Indigofera heterantha	Shrub	5	3	5	1	5	1	1	1	1	23	MV
Isodon rugosus	shrub	5	3	2	2	4	1	1	1	1	20	MV
Launaea nudicaulis	Herb	1	1	3	4	2	1	1	5	2	20	MV
Mallotus philippensis	Tree	1	3	4	3	2	1	1	1	1	17	MV
Melia azedarach	Tree	3	1	4	1	4	1	1	1	1	17	MV
Micromeria biflora	Herb	1	1	3	3	4	1	1	5	1	20	MV
Morus nigra	Tree	3	2	4	1	5	1	1	1	1	19	MV
Myrsine africana	Shrub	1	2	5	2	4	1	1	1	1	18	MV
Nerium oleander	Shrub	1	3	5	3	3	1	1	1	2	20	MV
Olea ferruginea	Tree	4	1	4	1	4	1	1	1	1	18	MV
Origanum vulgare	Herb	1	1	3	3	3	1	1	5	1	19	MV
Oxalis corniculata	Herb	3	4	3	2	4	1	1	5	1	24	MV

Parrotiopsis jacquemontiana	Shrub	4	3	5	2	5	1	1	1	1	23	MV
Pimpinella diversifolia	Herb	1	2	3	4	2	1	1	5	2	21	MV
Pinus roxburghii	Tree	2	1	4	1	4	1	1	1	2	17	MV
Pinus wallichiana	Tree	3	1	4	1	5	1	1	1	2	19	MV
Pistacia chinensis	Tree	1	3	4	3	2	1	1	5	1	21	MV
Plantago lanceolata	Herb	1	1	3	3	1	1	1	5	1	17	MV
Pteris cretica	Herb	1	4	3	4	1	1	1	5	2	22	MV
Quercus baloot	Tree	4	1	4	1	5	1	1	1	1	19	MV
Quercus incana	Tree	4	1	4	1	5	1	1	1	1	19	MV
Rhus punjabensis	Tree	1	2	4	3	2	1	1	4	2	20	MV
Rumex hastatus	Herb	2	1	3	2	4	1	1	5	1	20	MV
saccharum griffthi	Herb	1	1	1	3	2	1	2	3	1	15	HV
Sageretia thea	Shrub	3	1	2	2	3	1	1	1	1	14	HV
Salvia hians	Herb	1	4	3	3	1	1	1	5	2	20	MV
Sarcococca saligna	Shrub	1	1	5	3	2	1	1	5	1	20	MV
Scabiosa candollei	Herb	1	4	3	4	2	1	1	5	2	23	MV
Solanum surattense	Herb	1	2	3	3	3	1	1	5	1	20	MV
Solidago virgaurea	Herb	1	2	1	4	1	1	1	5	1	17	MV
Stipagrostis ciliate	Herb	1	4	3	4	2	1	1	5	2	23	MV
Tagetes minuta	Herb	1	2	3	3	2	1	1	5	2	20	MV
Themeda anathera	Herb	2	1	3	3	2	1	2	2	1	17	MV
Thymus linearis	Herb	3	1	3	3	2	1	1	5	1	20	MV
Viola biflora	Herb	1	2	3	3	2	1	1	5	1	19	MV
Zanthoxylam armatum	Tree	1	1	4	2	3	1	1	1	1	15	HV
Ziziphus jujube	Tree	1	1	4	1	4	1	1	1	1	17	MV

Discussion

The present study highlights the rich floristic and ethnobotanical diversity of Tehsil Khall, District Dir Lower, Pakistan. A total of 50 plant species belonging to 48 genera and 34 families were recorded, reflecting considerable taxonomic diversity in the study area (Abel and Busia, 2005). The dominance of Rosaceae (12%) and Papilionaceae (8%) is consistent with previous studies conducted in similar ecological regions (Ahmad *et al*., 2011; Ajaib *et al*., 2014; Ajaib *et al*., 2013; Azhar *et al*., 2015). Comparable patterns have also been reported in the Flora of Pakistan (Ali and Qaisar, 1995–2009), suggesting that these families are well adapted to the climatic and ecological conditions of the region (Becker, 2014). The predominance of non-spiny species (92%) indicates that the vegetation is largely composed of taxa adapted to relatively moderate environmental conditions, with limited grazing or arid stress pressures. In terms of growth forms, herbs constituted the majority (55.88%), followed by trees and shrubs (22.05% each) (Betti, 2004; Bekele and Reddy, 2015). This dominance of herbaceous species may be attributed to favorable seasonal conditions, short life cycles, and their ability to rapidly colonize open habitats, which is consistent with earlier findings (Choudhary *et al*., 2008; Devi and Muniyandi, 2015; Foo *et al*., 2016).

Seasonal variation further demonstrated that plant diversity peaked during spring (96%), followed by summer (84%), while comparatively fewer species were observed in autumn and winter (64%) (Garcia *et al*., 2007). The dominance of therophytes and nanophanerophytes during spring reflects optimal growth conditions, including suitable temperature and moisture availability. Similar seasonal patterns have been reported by Gilani *et al*. (2013), Hassan *et al*. (2015), and Hassan *et al*. (2015), indicating that climatic factors strongly influence plant phenology

and distribution. Ethnomedicinal analysis revealed the presence of 58 plant species belonging to 41 families and 50 genera, indicating a high level of traditional knowledge among local communities. Lamiaceae emerged as the most dominant medicinal family (10%), followed by Euphorbiaceae (6%) and Apiaceae (5%). This pattern reflects the well-known pharmacological importance of these families due to their rich secondary metabolites and bioactive compounds Hazrat *et al*., 2007. The use of plant parts showed a clear preference for leaves (25%), followed by whole plants (17%), roots (15%), and fruits (13%). This trend is consistent with ethnobotanical studies worldwide, where leaves are commonly used due to their accessibility, ease of collection, and high concentration of bioactive compounds (Hazrat *et al*., 2011). The predominance of whole plant usage also reflects traditional preparation methods and the holistic approach of indigenous medicine (Homervergel and Kim, 2014). In terms of therapeutic applications, cough-related treatments were the most common (18%), followed by anthelmintic, diuretic, and carminative uses (10% each) (Hussain *et al*., 2008). The frequent use of plants for respiratory and gastrointestinal disorders highlights the prevalence of these health issues in rural communities and the reliance on plant-based remedies for primary healthcare (Iain *et al*., 2005).

Several plant species recorded in this study exhibited important medicinal uses. For instance, *Berberis lyceum* is used for hepatitis and throat infections, *Cannabis sativa* as a tonic and narcotic, *Caralluma tuberculata* for diabetes, and *Foeniculum vulgare* as a carminative. Similarly, *Olea ferruginea* is used for joint pain and diabetes, while *Punica granatum* is used for digestive and urinary disorders (Ibrar *et al*., 2007). These findings are consistent with earlier reports from different regions of Pakistan (Islam *et al*., 2013; Kaigongi and Musila, 2015; Kamau *et al*., 2016; Jamila and Rahman, 2016), confirming the reliability of traditional knowledge. The study also revealed that local communities heavily depend on plant resources for their daily needs, with 40% of species used as fuel, followed by fodder (20%), furniture (16%), and vegetables (16%). Similar utilization patterns have been reported by Khan *et al*., (2012) and Jamila and Rahman, (2016), indicating that plant resources play a crucial role in sustaining rural livelihoods. The high dependence on fuelwood reflects the lack of alternative energy sources, which may contribute to the overexploitation of natural vegetation (Mahmood *et al*., 2011).

The widespread use of plants for fodder, fuel, and timber has been documented in various studies (Marwat *et al*., 2012), highlighting the pressure exerted on plant biodiversity. Human activities such as overgrazing, deforestation, and agricultural expansion significantly impact vegetation structure and lead to environmental degradation (Matthews and Medhi, 2014). Similar trends have been reported in other regions of Pakistan, including Salarzai Valley, central Punjab, and Neelum Valley (Mohamadi *et al*., 2015; Mohammadi *et al*., 2016). The findings of this study also align with previous reports on the use of edible and fodder plants. For example, the use of *Amaranthus viridis* as a vegetable and *Convolvulus arvensis*, *Cynodon dactylon*, and *Fumaria indica* as fodder is consistent with earlier studies (Mosaddegh *et al*., 2016; Negbenebor *et al*., 2017; Manan *et al*., 2025; Ullah *et al*., 2025). Overall, the study demonstrates that Tehsil Khall possesses rich floristic diversity and valuable ethnobotanical knowledge (Khan *et al*., 2024). However, increasing anthropogenic pressures and overexploitation of plant resources pose a serious threat to the sustainability of local flora (Ullah *et al*., 2019). Therefore, there is an urgent need for conservation strategies, sustainable utilization practices, and awareness programs to preserve both plant biodiversity and traditional knowledge for future generations.

Conclusions

The present study provides a comprehensive assessment of floristic diversity and ethnobotanical knowledge in Tehsil Khall, District Dir Lower, Pakistan. The findings reveal a rich diversity of plant species with significant taxonomic representation and strong dominance of herbaceous life forms. Seasonal variation indicates that plant diversity is highest during spring, reflecting favorable environmental conditions for plant growth. The study highlights the extensive reliance of local communities on plant resources for medicinal, nutritional, and domestic purposes. Leaves and whole plants were the most commonly used parts, while a wide range of species were utilized for treating various ailments, particularly respiratory and gastrointestinal disorders. The dominance of certain plant families, such as Rosaceae and Lamiaceae, further emphasizes their ecological adaptability and medicinal importance. Despite the rich biodiversity

and valuable traditional knowledge, increasing anthropogenic pressure and overexploitation pose potential threats to plant resources. Therefore, there is an urgent need for conservation strategies, sustainable harvesting practices, and documentation of indigenous knowledge to ensure the long-term preservation of plant diversity and its associated cultural heritage. Overall, this study contributes valuable baseline data for future pharmacological research, biodiversity conservation, and sustainable management of plant resources in the region.

Recommendations

- Awareness programs should be conducted among local communities to highlight the ecological and medicinal importance of plant resources.
- Local inhabitants should be encouraged to cultivate medicinal plants in home gardens, agricultural fields, and other suitable areas to reduce pressure on wild populations.
- Effective policies and legislation should be developed and implemented by relevant authorities to ensure the conservation and sustainable management of medicinal plants.
- Unsustainable practices such as overgrazing, indiscriminate cutting, and uncontrolled harvesting of plant species should be strictly regulated.
- Indigenous knowledge related to native and wild plant species, particularly their pharmacological potential, should be systematically documented and scientifically validated to support future research and drug development.
- Community-based conservation strategies should be promoted to ensure the long-term preservation of plant biodiversity and traditional knowledge systems.

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Novelty Statement

This study provides the first comprehensive documentation of floristic diversity and ethnobotanical knowledge in Tehsil Khall, District Dir Lower, Pakistan. It integrates plant diversity assessment with traditional medicinal uses, seasonal variation, and quantitative ethnobotanical analysis, offering new insights into plant utilization patterns and local healthcare practices. The findings contribute valuable baseline data for biodiversity conservation, sustainable resource management, and future pharmacological research, while also highlighting the importance of preserving indigenous knowledge systems in the region.

Author Contributions

Mohammad Sohail, Falaknaz, and Lubna Shakir: Contributed to data collection and field surveys.
Ghani Subhan and Naveen Dilawar: Assisted in data analysis and interpretation.
Ikram Ullah: Supported plant identification and manuscript preparation.
Shakir Ullah: Conceived and designed the study, supervised the research, and finalized the manuscript. All authors read and approved the final manuscript.

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The author's declare that no Gen AI was used in the creation of this manuscript.

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

Data availability
All data generated or analyzed during this study are included in this published article and its supplementary information files. Additional data are available from the corresponding author upon reasonable request.

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