Japan Journal of Research

Original Article

Prospects and Challenges for Biodiversity in the Anthropogenic-Induced Cold Arid Landscape of Ladakh, India

Mahesh Kumar Gaur[1], R.K. Goyal[1], M S Kanwar[2], Neelratan Singh[3], Vipin Choudhary[4], Akash Chichaghare[5]

[1]Principal Scientist, Regional Research Station, ICAR - Central Arid Zone Research Institute (CAZRI), The U.T. of Ladakh, India
[2]Principal Scientist & Head, Regional Research Station, ICAR - Central Arid Zone Research Institute (CAZRI), The U.T. of Ladakh, India
[3]Senior Scientist, CSIR - Central Institute of Mining & Fuel Research, Nagpur, MH, India
[4]Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur, India
[5]Scientist, Regional Research Station, ICAR - Central Arid Zone Research Institute (CAZRI), The U.T. of Ladakh, India

Correspondence

Dr Mahesh Kumar Gaur
Principal Scientist, Regional Research Station, ICAR - Central Arid Zone Research Institute (CAZRI), Stakna, Hemis Road, Leh-194 201, The U.T. of Ladakh. INDIA
E-mail: geo.maheshgaur@gmail.com

- Received Date: 04 Mar 2024
- Accepted Date: 15 Jun 2024
- Publication Date: 19 Jul 2024

Keywords

High-altitude deserts; Biodiversity; Ladakh; Landscape; Phytogeography; Halophytic Vegetation; Anthropogenic Factors

Abstract

Ladakh, a high-altitude cold arid region, exhibits conspicuous signs of climate change across its vast landscape. The unique biodiversity of Ladakh faces various challenges due to both exponential anthropogenic activities and the significant threat of climate change to the region's environmental landscape and physiographical variations. The region's unique topography, from high-altitude deserts to soaring Himalayan mountains, makes it a biodiversity hotspot. However, biodiversity is under threat from climate change, infrastructure development, the upward movement of invasive species, and water scarcity due to glacial retreat. There is enough potential to combine traditional ecological knowledge with modern conservation strategies. Climate change, with rising temperatures and glacial retreat, poses a significant threat to Ladakh's biodiversity, particularly that of alpine flora and fauna. Infrastructure development, including roads and hydropower projects, can fragment habitats and dislocate wildlife corridors, leading to reduced genetic diversity. Long-term field observations form the basis for an in-depth exploration of prospects and potential threats to the biodiversity of Ladakh's cold arid zone, emphasizing the role of anthropogenic factors in this study.

Introduction

Biodiversity, the intricate web of life on Earth encompassing all species of plants, animals, and microorganisms, is facing a dynamic and complex set of prospects and challenges in the current rapidly changing scenario. As human activities continue to reshape the planet, the potential for preserving and enhancing biodiversity and obstacles to its sustainability are more evident than ever before [1]. Ladakh boasts a wide variety of ecosystems, including cold deserts, alpine meadows, pristine lakes, and high-altitude forests [2]. These ecosystems support a plethora of flora and fauna, making them potential hubs for biodiversity conservation [3]. Its unique geographical features, ranging from high-altitude deserts to the towering Himalayan Mountains, make it a hotspot for biodiversity [4]. However, Ladakh's biodiversity faces both prospects and challenges in the rapidly changing scenario of the 21st century [5]. The region is home to several endemic species, such as the Ladakh urial, snow leopard, and Himalayan marmot. These unique species contribute to global biodiversity and can serve as flagship species for conservation efforts [6]. Ladakh's indigenous communities have coexisted with their natural surroundings for centuries [7,8]. The traditional knowledge and sustainable practices of these plants have contributed to the preservation of biodiversity [9,10]. There is potential for synergizing traditional ecological knowledge with modern conservation strategies [11]. Climate change poses one of the most significant threats to Ladakh's biodiversity [1]. Rising temperatures, erratic weather patterns, and glacial retreats can disrupt ecosystems and impact species survival. Alpine flora and fauna, adapted to cold climates, may face severe challenges [12,13]. The introduction of invasive species, often facilitated by human activities, can outcompete native species and disrupt local ecosystems [11,14]. These invaders can alter the natural balance of biodiversity [15,16]. Water scarcity in Ladakh, exacerbated by climate change, can lead to competition for limited water resources. This can affect both human communities and wildlife dependent on these water sources [17]. Ladakh's biodiversity is at a crossroads, facing both promising prospects and daunting challenges [18,19]. To ensure the continued existence of unique

Citation: Gaur MK, Goyal RK, Kanwar MS, Singh N, Choudhary V, Chichaghare A. Prospects and Challenges for Biodiversity in the Anthropogenic-Induced Cold Arid Landscape of Ladakh, India. Japan J Res. 2024;5(6):041

flora and fauna, a multifaceted approach is needed, including climate mitigation efforts, sustainable development practices, community engagement, and the integration of traditional knowledge with modern conservation methods [6,19-21]. Only through these concerted efforts, can Ladakh's biodiversity thrive in the changing scenario of the 21st century.

Study Area

Ladakh is an isolated region situated in the northwestern part of the Trans-Himalayan area and is popularly known as "Little Tibet". It extends over a sprawling area of nearly 100,000 square kilometres, stretching from approximately 75°50'E to 80°E longitude and 32°30' N to 37° N latitude. From a geographical perspective, Ladakh marks the westernmost extension of the immense Tibetan Plateau. Its elevation varies significantly, ranging from 2700 to 7650 meters above sea level (Figure 1). The region is naturally bounded by two major mountain ranges: the formidable Himalayas to the south and the imposing Karakoram range to the north [14,22]. In addition, the region is intersected by the flow of the Indus River, and Ladakh is further characterized by the Zanskar and Ladakh ranges. Precipitation in this part of the Himalayan range is inadequate, typically averaging between 80 to 1000 millimetres annually, primarily occurring during the winter season [23]. The precipitation varies from 757 mm at Drass, and decreases towards the northeast, to approximately 306 mm in Kargil and as little as 115 mm in Leh, which renders it extremely arid [8,17]. This leads to heavy snowfall in the Drass, Suru, and Zanskar valleys. However, this seasonal snowmelt contributes to moderate vegetation growth in the lower valley floors during the summer months [24]. Conversely, the eastern and northwestern regions of Ladakh, bordering Tibet, mainly consist of high-altitude, cold, open plains, rolling hills, and broader valleys [5,15,17]. Due to less than 100 mm of annual rainfall, the vegetation in these regions is sparse, creating an arid, desert-like environment [12]. A few remnants of the extensive lake system remain, such as Pagong-Tso, Tso-Mori, Tso-Kar, Tsigul-Tso, and extensive marshes near Hanle, Chumur, and Chushul [19].

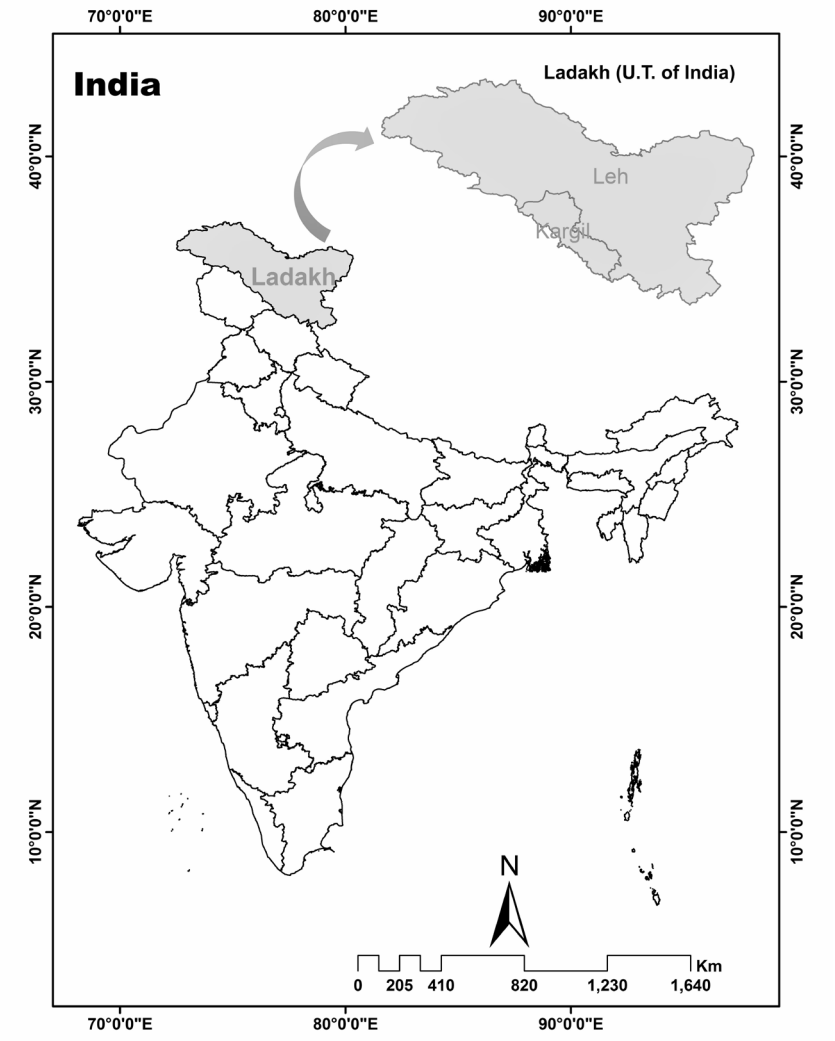

Figure 1. *Location of the Study area i.e. Ladakh*

Human settlements in Ladakh are primarily found in the Indus Valley, which is the main river in the region originating from Tibet and flowing through Ladakh in a southeast-to-northwest direction [15]. In the winter months, Ladakh experiences arctic-type extremely cold conditions, with temperatures often dropping well below the freezing point (-30°C to -40°C) [8,25]. However, despite its proximity to torrential monsoon rains, Ladakh enjoys a short but pleasant summer season. This period typically extends from June to mid-September. During this brief season, thousands of tourists visit the region every year [11,26]. They are mainly drawn to Ladakh by its rich and unspoiled heritage, and its captivating landscapes. Agri-horti-silviculture and Agri-pastoral are the farming systems in the region and mono-cropping is practiced in Ladakh whereas; double cropping is undertaken in some parts of the Kargil district, Sham belt and Nubra valley of the Leh district [11,19].

Demography and Land Use Changes

Land use depends upon various physical and human factors such as terrain, soil, climate, population density, occupation and technological advancement [27]. Since the region lies in the rain-shadow area, it is one of the driest places on earth. Under these harsh conditions, agriculture is difficult to practice [28]. Nevertheless, by diverting glacial-fed rivers into stone-built terraces, gathering soil through sedimentation, enriching the soils with organic manure and other practices, local people have been able to cultivate staples. Therefore, traditional Ladakh agriculture is unique and is representative of the Tibetan Plateau [11].

The population of Ladakh is relatively small. In 2021, the population was estimated to be approximately 274,000 people. The majority of the population in Ladakh resides in rural areas, where agriculture and pastoralism are important economic activities. Leh and Kargil are the largest towns in the region and serve as the main urban centres. The Leh district has a population of 133,487 persons; among males are 78971 and for females are 54516. The density of the population is approximately three persons per sq. km. The decadal growth rate of the district was 13.86%. There are 16 blocks in the district. The sex ratio in the district is 690 females per 1000 males and the literacy rate is 77.2%. There was an 11.68% net change in urbanization in the Leh district, and 3.59% in Kargil district and an overall change of 6.82% occurred in the Ladakh UT during 1981-2001. Similarly, the net change in urbanization was 9.78% in the Leh district, 2.67% in the Kargil district and an overall change of 6.0% for Ladakh UT during the 2001–2011 period [11].

Table 1. *Demographic profile of Ladakh (in percentages)*

Year	Rural / Urban	Leh District	Kargil District	Union Territory of Ladakh	Rate of urbanization		
					Leh	Kargil	Ladakh
1981	Rural	87.28	94.66	90.21	12.75	5.34	9.79
	Urban	12.75	5.34	9.79			
2001	Rural	75.57	91.07	83.39	24.43	8.93	16.61
	Urban	24.43	8.93	16.61			
2011	Rural	65.79	88.40	77.39	34.21	11.60	22.61
	Urban	34.21	11.60	22.61			

Sources: (1) Primary Census Abstract of Leh and Kargil district, Census of India 1981.
(2) Primary Census Abstract of Jammu & Kashmir (Compact Disk), Census of India 2001.
(3) Primary Census Abstract of Jammu & Kashmir, Census of India 2001, www.censusoindia.gov.in

Table 2. *Changes in land use patterns in Leh district (1985-86 to 2018-19)*

Year	Area (in ha.)	Area not Available for Cultivation*	Cultivable Wasteland Excluding Fallow*	Fallow Land*	Net area sown*	Area sown more than once*	Total Cropped Area*
1985-86	44479	60.2	16.3	1.50	21.9	NA	NA
1990-91	45167	62.3	14.7	1.10	21.9	NA	NA
1995-96	45167	62.1	14.6	1.20	22.0	NA	NA
2000-01	45167	62.1	12.3	0.90	24.70	NA	NA
2005-06	51352	65.4	13.85	0.89	19.84	0.78	20.61
2010-11	51684	66.26	13.77	0.80	19.73	2.89	22.62
2015-16	45167	67.42	9.51	1.04	21.97	1.37	23.34
2018-19	45611	67.69	28.1	0.11	22.00	0.71	22.71

* Percentage of total reporting area (PTRA)
Source: (1) LAHDC Statistical Handbook, Leh; and (2) Financial Commissioner (Rev.) J&K

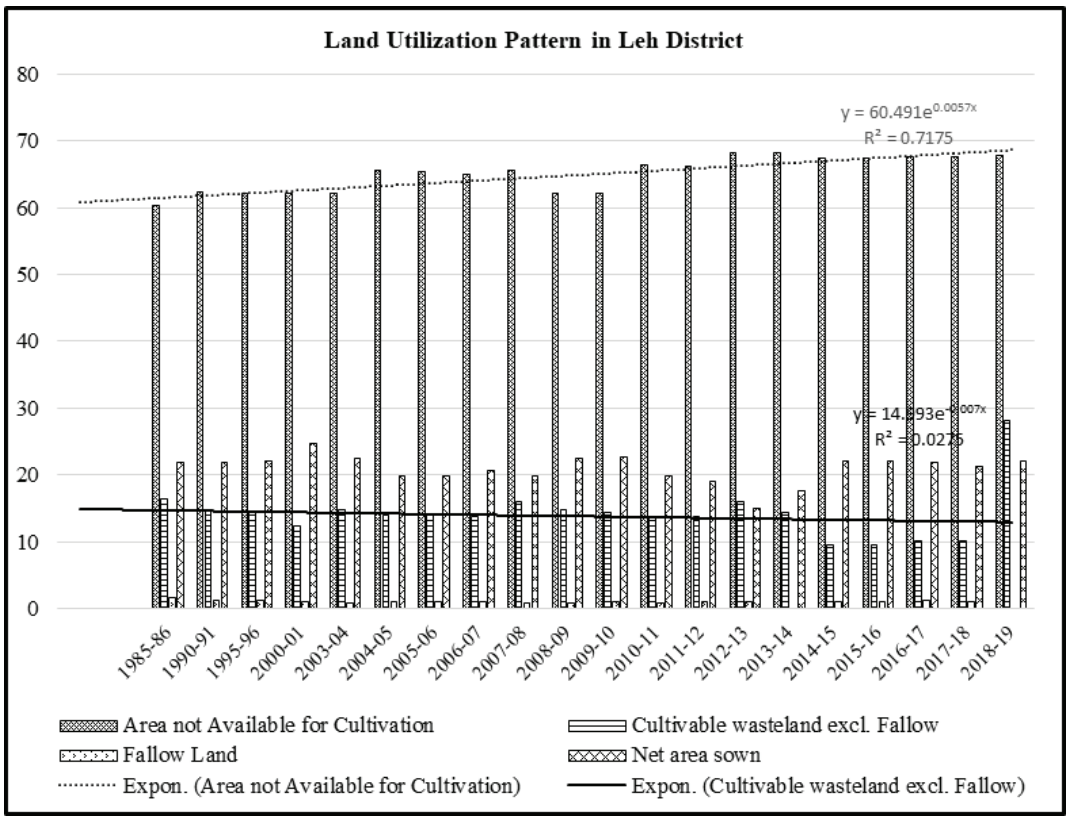

Figure 2. *Land utilization pattern in Leh District*

Table 2 describes the relative changes in the land use patterns in the Leh district. The overall maximum stake of the land use class to the reporting area during these decades was an *area not available for cultivation* (67.7%) in 2018-19 whereas the area under *fallow land* was hardly 0.11% during the same period. For each land use class, the total reporting area had a maximum to minimum stake. The land use class of *area not available for cultivation* had a maximum of 68.13% in 2012-13 whereas it had a minimum stake of 60.2% in 1985-86. The maximum stake of the land use class of *cultivable wasteland excluding fallow land* was 28.1% in 2018-19 but was nearly 9.5% in 2015-16 [11].

The 1985-86 data show that the maximum stake of fallow land was 1.5% of the total reporting area, whereas no land was recorded as fallow land in 2013-14. The *area under net sowing* was highest during 2000-01 (24.7%) which declined to 14.9% in 2012-13. On average, the area not available for cultivation had the highest stake among the land use class to the total reporting area during all these years (from 1985-86 to 2018-19) (Figure 2).

The highest stake of the land use class of *land put to non-agricultural uses* occurred from 2016 to 2018 (16.2%) whereas its lowest stake was found in 1985-86 (4.1%). However, the relative change in the land use stake of land put to non-agricultural use was 147.9% between 2003-04 (0.01%) and 2012-13 (-59.0%). Similarly, the maximum stakes of the land use class of barren and uncultivable land to the total reporting area occurred in 2012-13 and 2013-14 (61.7%) whereas the

Table 3. *Number of land holdings by different sizes and classes in Leh District*

Class and Size		2005-06				2010-11				2015-16			
		Area (ha.)	% age area	No. of hold-ings	% age hold-ings	Area (ha.)	% age area	No. of hold-ings	% age hold-ings	Area (ha.)	% age area	No. of hold-ings	%a ge hold-ings
Marginal	Upto 1 ha	6105.0	34.1	19410	77.89	5281.91	36.5	17306	80.47	5312.35	36.1	17320	80.4
Small	1 – 2 ha	4988.4	27.9	3563	14.3	4010.62	27.7	2875	13.37	3921.85	26.7	2818	13.08
Semi-medium	2 – 4 ha	4278.6	23.9	1620	6.5	2967.77	20.5	1124	5.22	3038.7	20.7	1141	5.3
Medium	4 – 10 ha	1596.8	8.9	280	1.12	876.88	6.1	160	0.75	1202.8	8.2	216	1.0
Large	10 & above	935.7	5.2	48	0.19	1328.41	9.2	40	0.19	1222.5	8.3	47	0.22
Total		17904.5	100.0	24921	100.0	14466.6	100.0	21505	100.0	14698.2	100.0	21542	100.0

Source: - Agriculture Census of different years and publications of LAHDC.

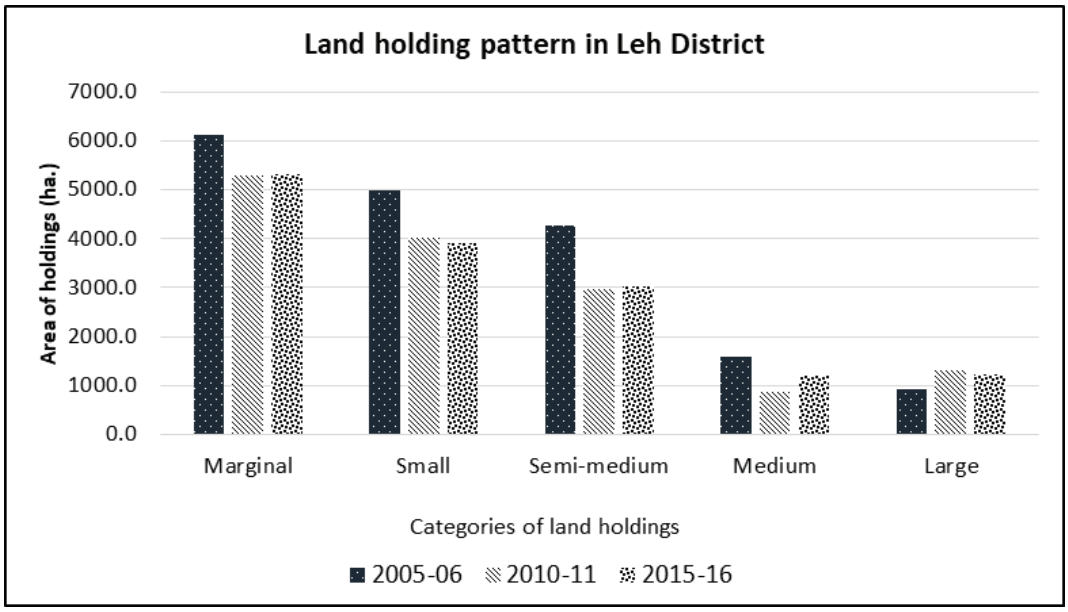

Figure 3. *Land Holding Pattern in Leh District*

minimum representation occurred in 2006-07 (51.2%). The data on the relative change indicate a maximum though negligible increase of 8% in the stakes of the same between 2009-10 (0.0%) and 2010-11 (8%). Double cropping is undertaken in some parts of the Kargil, Khaltsi and Nubra subdivisions [29].

According to the tenth agricultural census, the number of marginal, semi-medium, medium and large agricultural land holdings in the Leh district (known as operational holdings) registered a marginal increase during 2015-16 compared to 2010-11 (Table 3). This means that more people now own marginal parcels of agricultural land. It also shows that out of a total of 21,542 operational holdings, only 14698.2 ha are within the operational area. There is a consolidation of land holdings in the semi-medium, medium and large holdings in the district. With a positive development, the percentage of women landholders has increased [11]. This shows that an increasing number of females are participating in the management and operation of agricultural lands (Figure 3).

Phytogeography and Vegetation Zones

Ladakh is known for its unique phytogeography and vegetation zones due to its high altitude, arid climate, and rugged terrain. The vegetation in Ladakh is sparse and adapted to extreme environmental conditions [30]. Ladakh is divided into four distinct phytogeographical regions with characteristic vegetation types: (1) the Karakorum region, which includes the northern part of the Ladakh range, and extends to the east into the upper Indus valley; (2) the Inner Northwest Himalayan or Western Himalayan region, which includes the southern and western parts of Ladakh, lower Indus valley, Suru, Drass and Zanskar [31]; (3) the Southwest Tibetan region, which comprises the southwestern part of Ladakh; and (4) the North Tibetan or Changthang region, which comprises Pangong, the upper Shyok valley and Aksai Chin [1,23,32]. The flora of Ladakh contains approximately 880 species [33-36]. The primary vegetation zones and the phytogeography of Ladakh are given below:

Trans-Himalayan region

The Trans-Himalayan region of Ladakh, also known as the *Ladakh Desert*, is an arid and high-altitude desert landscape with unique phytogeography and vegetation [31]. This region is characterized by extreme environmental conditions, including high elevations, cold temperatures, low precipitation, and rocky terrain [37,38]. The vegetation in the Trans-Himalayan region of Ladakh is adapted to these harsh conditions and consists of several distinctive plant species and communities [34,39].

Ladakh Desert

This region is characterized by extreme aridity and is often referred to as a cold desert. The vegetation cover is minimal and includes drought-resistant plants such as xerophytes and succulents.

Drought-Resistant Xerophyte

Many plants in the Trans-Himalayan region have adapted to the arid climate by developing xerophytic traits, which help them conserve water. These plants often have small, thick leaves or no leaves at all, reducing water loss through transpiration. Various species of saxaul (*Haloxylon* spp.) are small, leafless shrubs that can tolerate extreme aridity [40]. These xerophytes have developed a range of specialized adaptations to conserve water and thrive in Ladakh's challenging environment [9]. Some of the notable drought-resistant xerophytes found in Ladakh are as follows:

Saxaul (*Haloxylon* spp.): Saxaul is a common xerophyte in Ladakh, particularly in desert regions. These small, woody shrubs have reduced leaves to minimize water loss through transpiration. They plants are well adapted to survive in saline and arid soils.

***Artemisia* spp.:** Several species of *Artemisia*, commonly known as wormwood or sagebrush, are found in Ladakh. These aromatic shrubs have adapted to arid conditions with finely divided leaves that reduce water loss.

***Ephedra* spp.:** *Ephedra*, also known as jointfir or horsetail, is a unique xerophyte with slender, jointed stems. These plants have reduced leaves and rely on photosynthesis via their green stems. These are well-suited to Ladakh's arid regions.

***Caragana* spp.:** *Caragana* bushes, also known as pea shrubs, are drought-resistant and are found in Ladakh. These plants are known for their nitrogen-fixing abilities, which improve soil fertility in the cold arid area of Ladakh.

Myricaria germanica: Locally it is known as Umbu. This shrub is found in the plain region of the Chiktan Valley. The plant is used as fuel and fodder [41]. The above-ground dried parts of the plants were used for roof construction. The plants were spread over the twigs and logs before being covered with mud and soil. It is also used for fencing fields and as a tree guard for protecting sapling of Salix from animals such as cows and donkeys.

***Rheum* spp.:** *Rheum*, or rhubarb, is a genus of herbaceous perennials that includes drought-resistant species. They have large, fleshy leaves and deep root systems that allow them to store water for extended periods.

***Allium* spp.:** Some species of *Allium*, such as wild onions and garlic, are found in Ladakh. These plants have adaptations, such as having succulent leaves that store water and help them survive during dry periods.

***Sedum* spp.:** *Sedum* species, including *Sedum himalayanum*, are succulent xerophytes that store water in their fleshy leaves. These species are well-suited to Ladakh's arid conditions and are found in rocky and high-altitude areas.

***Salsola* spp.:** *Salsola*, or saltwort, is a xerophytic plant that can tolerate saline soils. It has slender, succulent leaves and is adapted to arid and saline conditions.

These drought-resistant xerophytes play a crucial role in Ladakh's ecosystem by providing habitat and food for wildlife and serving as a source of traditional medicine and forage (*Cicer, Echinops, Eurotia, Nepeta, Medicago*) for livestock [42]. They are also an essential component of the region's unique phytogeography and have evolved to thrive in one of the world's most challenging cryospheric environments [10].

Succulents

Some succulent plants, such as the Himalayan Stonecrop (*Sedum himalayanum*), are found in this region. These plants store water in their fleshy leaves and stems to survive long periods of drought.

Himalayan Stonecrop (*Sedum himalayanum*): This succulent plant is native to the Himalayas, including Ladakh. It has fleshy, round leaves and produces clusters of small, star-shaped pink flowers [43]. It commonly grows on rocky slopes and cliffs.

Himalayan Rhubarb (*Rheum* spp.): Although not a typical succulent, the Himalayan rhubarb has large, fleshy leaves and can store water in its stems. It is well-adapted to Ladakh's arid conditions and can be found in rocky areas.

***Rosularia* spp.:** *Rosularia* is a genus of succulent plants that includes several species found in Ladakh. These plants have rosette-shaped clusters of fleshy leaves and produce small, star-shaped flowers [43]. These plants often grow in rocky crevices [41].

Ladakh Hen and Chicks (*Sempervivum ladakhicum*): This species of *Sempervivum*, commonly known as "hen and chicks," forms tight rosettes on fleshy leaves. It is well-suited to cold, rocky environments and can be found in Ladakh's high-altitude areas.

***Sedum stellatum*:** Another sedum species, *Sedum stellatum*, is found in Ladakh. It has small, succulent leaves and produces clusters of white or pinkish flowers [41,43]. It thrives on rocky terrain.

***Orostachys spinosa*:** *Orostachys spinosa* is a hardy succulent with spiky, green rosettes on its leaves. It can tolerate cold temperatures and is found in high-altitude regions of Ladakh.

***Sedum acre*:** *Sedum acre*, also known as the gold moss stone crop, is a low-growing succulent crop with small, bright green leaves. It is well-adapted to arid environments and is found in Ladakh's rocky outcrops.

These succulent plants have developed specialized adaptations to store water and survive in Ladakh's cold arid climate. They are an important component of the region's unique flora, providing habitat and sustenance for wildlife and contributing to the overall biodiversity of this challenging environment [44].

Halophytic Vegetation

Ladakh is known for its unique halophytic vegetation. In areas with saline or salt-rich soils and along riverbanks, lakeshores, streams and depressions where salts accumulate, halophytic vegetation is found [19]. These plants are adapted to tolerate high levels of soil salinity. The species found are *Seidlitzia rosmarinus* and *Suaeda* spp. Some of the halophytic vegetation in Ladakh include the following:

***Suaeda* spp. (seepweed):** Various species of *Suaeda* are common halophytes in Ladakh. These plants have succulent leaves and can tolerate saline soils. *Suaeda* species are often found in low-lying areas, riverbanks, and lake margins.

***Salicornia* spp. (Glasswort):** *Salicornia* species, also known as glasswort or pickleweed species, are another group of halophytic plants that can thrive in saline environments. These plants had jointed stems and small, fleshy leaves. Salicornia species are found in salt-affected soils in Ladakh.

***Kochia* spp. (summer cypress):** *Kochia* is a halophyte that is adapted to saline soils. It has small, densely packed leaves and appears silvery or grayish. Kochia is commonly found in the Ladakh region.

Tamarisk (*Tamarix* spp.): Tamarisk, also known as salt cedar, is a halophytic shrub that is well adapted to saline soils. It has feathery foliage and is found near riverbanks and in low-lying areas where salt accumulates.

***Lycium* spp. (Boxthorn):** Some species of *Lycium*, commonly known as boxthorn or wolfberry, are halophytes found in Ladakh. The plants have spiny branches and can tolerate saline conditions.

***Halocnemum strobilaceum*:** This halophyte has slender stems and tiny, scale-like leaves. It is well-suited to saline soils and is found in salt pans and salt flats in Ladakh.

Other halophytic plants found in the salt marshes include *Puccinellia himalaica, Polygonum sibiricum*, *Carex moorcroftii, Halerpestes sarmentosa, Kobresia schoenoides, Calamagrostis holciformis, Potentilla multifidi,* and *Leymus secalinus.* These halophytic plants have adapted to the challenging saline conditions of Ladakh, and they play a crucial role in stabilizing soils, preventing erosion, and providing habitats for various wildlife species. Additionally, some of these halophytes have economic and ecological value, as they are used for forage or in traditional medicine [42]. However, human activities, such as urbanization and agriculture, negatively impact these unique plant communities and their associated ecosystems [6].

Conservation efforts are important to protect and preserve the halophytic vegetation of Ladakh.

Alpine Desert

At higher altitudes, the vegetation becomes even scarcer. The vegetation in the alpine desert region of Ladakh is adapted to extreme cold, limited precipitation, and rocky terrain. Some hardy grasses and small shrubs are found there, but overall, the landscape is barren and rocky. It comprises much of the Indus valley beyond Leh city and includes tributary valleys such as Drass, Suru, Zanskar, and Shyok in Nubra, Beyond Shyok; additionally, it comprises semi-desert vegetation [45]. The important vegetation of this zone includes species of *Capparis, Haloxylon, Krascheninnikovia, Lycium, Perovskia, Corydalis, Echinops, Lepidium, Nepeta, Peganum, Bassia, Halogeton* and *Hippophae [7]*. Some of the key features of the vegetation in the alpine desert of Ladakh are as follows:

Sparse Vegetation: The alpine desert of Ladakh is known for its minimal and scattered vegetation. Harsh climatic conditions make it challenging for plants to establish themselves, resulting in low plant cover.

Mosses and Lichens: Mosses and lichens are common in alpine desert regions, particularly in damp areas, crevices, and near water sources. These small, non-vascular plants can tolerate cold and low moisture conditions [34].

Sedges and grasses: In slightly more favorable microhabitats with better moisture availability, sedges and grasses are found. These plants are adapted to the alpine environment and provide forage for wildlife (Singh and Gupta, 1990) [44].

Shrubs: Some hardy shrubs, such as species of *Juniper,* are found in the alpine desert, especially in sheltered valleys and near water bodies.

Herbs and Wildflowers: A few herbaceous plants and wildflowers are found in the alpine desert, but are relatively rare [43]. These plants often grow in rocky and well-drained soil conditions [41].

Endemic and Rare Species: The alpine desert of Ladakh is home to several endemic and rare plant species that have evolved to survive under these extreme conditions. The species *Corydalis adiantifolia, Astragalus oxydon, A. tribulifolius, Inula rhizocephala, Saussurea thomsonii, Senecio tibeticus, Braya aenea, Waldhemia vestita* and *Acantholimon lycopodioides* are 'endemic' or 'near endemic' to Nubra and adjacent ranges of Ladakh [16,46]. The endemic and rare plant species found in the alpine desert of Ladakh [41,43] are as follows:

Ladakh poppy (*Papaver rupifragum* var. *ladakhicum*): This poppy species is endemic to Ladakh and is known for its bright orange-red flowers. It is typically found in rocky and gravelly areas at high altitudes.

Ladakh Primrose (*Primula griffithii*): Ladakh Primrose is a rare and beautiful flowering plant that grows in moist areas along streams and in rock crevices. It displays clusters of pink to purple flowers.

Ladakh Euphorbia (*Euphorbia stracheyi*): This endemic *Euphorbia* species is adapted to the harsh alpine desert conditions of Ladakh. It has fleshy stems and small greenish-yellow flowers.

Ladakh Borage (*Borago ladakhiana*): This rare and endemic plant is characterized by its blue, bell-shaped flowers and is typically found on rocky terrain and slopes.

Himalayan Knotweed (*Polygonum polystachyum*): This rare species of knotweed is found in the alpine regions of Ladakh. It has lance-shaped leaves and produces pink or white flowers.

***Saussurea* spp. (*snow lotuses*):** Various species of *Saussurea*, commonly known as snow lotuses, are found in the alpine desert of Ladakh. These plants are known for their large, showy flower heads and are adapted to high-altitude conditions.

***Saxifraga* spp. (*Saxifrages*):** Several species of *saxifrages* are found in Ladakh, and some of them are endemic to the region. These plants typically grow in rocky areas and have rosettes of succulent leaves.

***Androsace* spp. (Rock Jasmine):** Rock jasmines belong to the Androsace genus, and some species are found in the alpine desert of Ladakh. These plants have small, star-shaped flowers and form tight rosettes on their leaves.

***Gentiana* spp. (Gentians):** Some species of gentians, such as *Gentiana algida*, are found in Ladakh's alpine regions. These perennial herbs produce striking blue flowers.

These endemic and rare plant species add to the unique biodiversity and ecological significance of Ladakh's alpine desert. Additionally, the alpine desert ecosystem of Ladakh is highly fragile and sensitive to environmental changes [18,19]. Climate change, overgrazing, and human activities heavily influence this unique vegetation and are likely to disturb the delicate balance of the ecosystem [1,2]. Conservation efforts are crucial for preserving the biodiversity and ecological integrity of this high-altitude desert region.

Sub-Alpine Region

The sub-alpine region of Ladakh, which typically spans altitudes ranging from approximately 3,000 to 4,000 meters (approximately 9,800 to 13,100 feet) above sea level. It has a distinct vegetation zone characterized by a greater variety of plant life compared to that in higher alpine desert regions [19]. In this sub-alpine region, conditions are somewhat less extreme in terms of cold and aridity, allowing for a more diverse range of plant species to thrive. The steppe vegetation is dominated by *Artemisia brevifolia, Astragalus oplites, Nepeta discolour, Rheum webbianum, Scorzonera virgat, Stipa orientalis* and *Lonicera microphylla.* Sparse forests of *juniper* and willow are predominantly found, particularly along riverbanks and in valleys [4]. The species commonly used as fodder (Figure 4) are *Artemisia dracunculus, Astragalus adesmifolius, A. confertus, A. oxydon, Bromus inermis, B. oxydon, Calamogrostis emodensis, Eragrostis pilosa, Festuca kashmeriana, Heracleum pinnatum, Lactuca tatarica, Lindelofia anchusoides, L. stylosa, Oxytropis cahsemiriana, O. tatarica, Poa bulbosa, P. falconeri, P. stapfiana, Stipa sibirica* and *Ulmus wallichiana* [16].

Some of the prominent features of vegetation in the sub-alpine region of Ladakh are s follows:

Sparse Forests

In sheltered valleys and areas with relatively more moisture, sparse forests of juniper (*Juniperus* spp.) are found. These coniferous trees are adapted to withstand the cold and arid conditions of Ladakh.

Willow trees (*Salix* spp.)

Willows are generally found in the sub-alpine regions, especially along the banks of rivers and streams. Compared with other trees, their ability to tolerate wetter conditions makes them more suitable for riparian areas.

Grasses and Forbs

The sub-alpine region supports a variety of grasses and forbs. These include alpine meadow grasses and herbaceous plants,

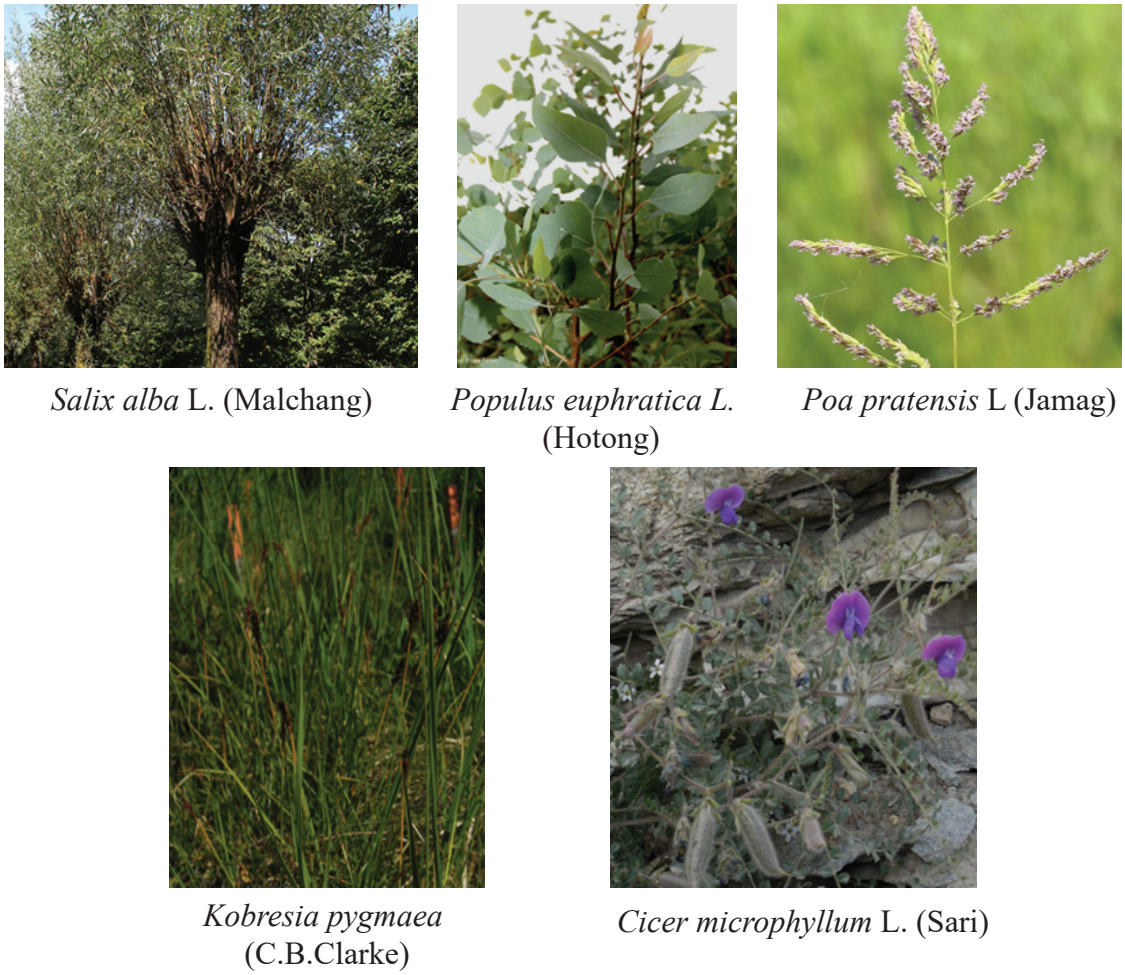

Figure 4. *Important fodder plants of Ladakh*

Field photos: M.S. Kanwar

which provide forage (*Cicer, Echinops, Eurotia, Nepeta, Medicago* spp.) for livestock and are important for the region's traditional agriculture [11,42].

Edible Plants

Several edible plants (*Urtica, Rhodiola, Capparis, Carum, Nepeta*), such as wild strawberry plants (*Fragaria* spp.), are found in the sub-alpine region. *Amaranthus spinosus* Willd., *Capsella thomsonii, Allium thomsonii, Lactuca dolichophylla, Chenopodium foliolosum, Lepidium latifolium, Orobanche hansii* and *Polygonum aviculare* are important wild food plants that are used as vegetables. The species commonly used as fodder include *Artemisia dracunculus, Astragalusadesmifolius, A. confertus, A. oxydon, Bromus inermis, B. oxydon, Calamogrostis emodensis, Eragrostis pilosa, Festuca kashmeriana, Heracleum pinnatum, Lactuca tatarica, Lindelofia anchusoides, L. stylosa, Oxytropis cahsemiriana, O. tatarica, Poa bulbosa, P. falconeri, P. stapfiana, Stipa sibirica* and *Ulmus wallichiana*. These plants are foraged by local communities and are also used in traditional medicines [42,47].

Berries and Medicinal Herbs

The sub-alpine region hosts various berry-bearing shrubs, including raspberries and currants. Species of *Delphinium, Aquilegia fragrans, Aster flaccidus, Lychnis nutans, Malva verticellata, Dianthus angulatus, Epilobium angustifolium, Potentilla curviseta, Rosa webbiana, Primula macrophylla, Perovskia abrotanoides, Rheum speciforme* and *Tanacetum tibeticum* have good potential to serve as ornamental and medicinal plants. Additionally, medicinal herbs are collected and used in traditional medicine practices [21,48].

Thorny Shrubs

Thorny shrubs, such as *Berberis* spp. *Atriplex hortensis, Ephedra gerardiana, Hippophae rhamnoides, Sophora moorcroftiana, Tanacetum tibeticum, Rosa webbiana, Berberis ulicina, Myricaria germanica, Tamarix gallica,* and various species of Salix and Populus are used as fuel. *Morus alba* and several other lesser-known fruit trees have the potential to improve the economy of the local people and are found in the sub-alpine region. These shrubs have adapted to harsh conditions and produce small, brightly colored berries.

Ferns and mosses

Ferns and mosses are present in damp and shaded areas, such as near streams and in forested patches within the sub-alpine region.

The sub-alpine region of Ladakh, which has a relatively milder climate than does the higher altitudes, supports a greater diversity of vegetation [19]. This unique vegetation is important for local communities because it provides resources for traditional livelihoods, such as grazing and agriculture, and contributes to the overall biodiversity of the region [1,2,18].

Alpine Region

The alpine region of Ladakh extends to altitudes above 4,000 meters (approximately 13,100 feet). It is characterized by extreme conditions, including cold temperatures, low oxygen levels, and rocky terrain and is dominated by alpine meadows and pastures [4]. The most distinctive vegetation type of the alpine belt is moist alpine turf with *Kobresia pygmaea.* These areas are important for grazing livestock and provide habitat for various wild herbivores, such as the Tibetan wild ass (*kiang*) and the ibex [2]. The vegetation conditions of the alpine region of Ladakh are as follows:

Alpine Meadows

The alpine region of Ladakh is known for its extensive alpine meadows (*Kobresia, Carex, Potentilla,* and *Nepeta*), often referred to as "*bugyals*" in local parlance. These meadows are covered with a variety of herbaceous plants and grasses that are adapted to cold and rocky terrain.

Cushion plants

Cushion lants are also known as "pin-cushion" plants. These plants are well-suited to the harsh conditions of the alpine region. These plants form low, dense mats with tightly packed leaves, which help them retain heat and protect against desiccation. *Arenaria* spp. and *Saxifraga* spp. are common species found here.

Sedges and Grasses

Cold and high-altitude adapted sedges and grasses are found in alpine meadows and provide forage for wildlife and domesticated animals [42].

Herbs and Wildflowers

Despite these extreme weather conditions, several herbaceous plants and wildflowers (*Aconitum, Podophyllum, Dactylorhiza,* and *Arnebia*) are found in the alpine region [43]. They often grow in sheltered spots or near water sources and produce colorful blooms during the short growing season [41].

Mosses and Lichens

Mosses and lichens are common in damp and shaded areas, including rock crevices and near streams. These non-vascular plants can tolerate cold temperatures and low moisture levels [34].

Small shrubs and trees

Small shrubs and trees are found in slightly more favorable microhabitats with better moisture availability. Juniper (*Juniperus* spp.) is a tree species adapted to alpine conditions [4].

High-altitude flora

Several alpine plant species in Ladakh are adapted to even higher altitudes and are found on the slopes of the region's towering peaks [41]. Xerophytic species such as *Echinops cornigerus, Caragana brevifolia, Ephedra gerardiana, Capparis spinosa,* and *Salsola collina* are found.

The alpine region of Ladakh is ecologically significant because it provides grazing grounds for livestock and plays a role in traditional agriculture [2,11]. It is essential to protect and conserve this unique and fragile ecosystem and its diverse vegetation.

Nival Region

The nival region in Ladakh refers to the highest elevation zone, typically above 5,000 meters (approximately 16,400 feet) in altitude. This zone is characterized by extreme cold temperatures, snow cover throughout much of the year, and a very short growing season, which limits the establishment of vegetation. Due to these extreme conditions, the nival region of Ladakh is largely devoid of vegetation, and plant life is limited. The characteristic vegetation of this zone includes *Aphragmus oxycarpus, Poa attenuate, Saussurea inversa, Stellaria decumbens* and *Waldheimia tridactylites.* The significant characteristics of the nival vegetation zone are as follows:

Snow and Ice

The nival region is dominated by snow and ice, and much of the land remains snow-covered for the majority of the year. Only during a brief summer period, when temperatures rise slightly, the snow melt to expose the bare rocky terrain.

Minimal Vegetation

Harsh conditions make it difficult for most plants to survive at such high altitudes. As a result, the nival region is characterized by sparse and very limited cover of vegetation such as *Poa attenuata* and *Potentilla sericea*.

Mosses and Lichens

In some of the less harsh microenvironments within the nival zone, mosses and lichens have been found at a height of 6000 m in the Zanskar Valley, which is situated in western Ladakh. These non-vascular plants can tolerate cold temperature and are found in rock crevices and on some of the exposed surfaces. The dominance of the species of the lichen families Lecanoracea, Acarosporaceae, Catillariaceae and Candelariaceae has been recorded [49]

Cushion Plants

In areas where snow has melted, cushion plants (e.g., *Arenaria* spp. and *Saxifraga* spp.) adapted to extreme cold conditions are present. These plants form low, dense mats close to the ground to protect against desiccation and cold temperatures.

Endemic Species

Several endemic and specialized plant species have adapted to the harsh conditions of the nival region. These species are highly specialized and adapted to extreme cold conditions, limited water availability, and intense solar radiation.

Algae and Cyanobacteria

In some areas where snow has melted, algae and cyanobacteria, which are photosynthetic microorganisms are found (*Phormidium* spp. and *Microcoleus vaginatus*) as these can survive in extreme conditions, including on glaciers and snowfields.

Bare Rocks

Much of the nival region consists of barren rocky surfaces, often referred to as "alpine deserts," where even the hardiest plants struggle to establish themselves.

Therefore, the nival region in Ladakh is a stark and challenging environment, and the presence of vegetation is minimal due to extreme climatic conditions. However, the region is ecologically significant because it provides a habitat for certain specialized species adapted to these extreme conditions. It is also an important water source because the melting snow and ice contribute to the flow of rivers and streams in lower-altitude regions.

Riparian Vegetation

Riparian vegetation in Ladakh refers to the plant communities that grow along the banks of rivers, streams, and other water

bodies in the region. This kind of vegetation includes willow trees, shrubs, and grasses. These areas are characterized by relatively higher moisture levels than the surrounding arid landscape, making them important not only for plant diversity but also for providing habitat for wildlife species (including birds, insects, and amphibians), water quality (by filtering pollutants and sediment), and soil stabilization (by preventing erosion along riverbanks). The features of the riparian vegetation in Ladakh are s follows:

Willow trees (*Salix* spp.)

Willows are common riparian plants in Ladakh. They have deep roots that can access groundwater, allowing them to survive in cold arid regions.

Poplar trees (*Populus* spp.)

Poplar trees are found near rivers and streams, and their tall stature provides shade and habitat for birds.

Tamarisk (*Tamarix* spp.)

Tamarisk, also known as salt cedar, is well-adapted to saline soils and is found along the banks of salt-laden rivers.

Riparian Grasses

Various grass species grow in riparian zones, and provide forage for livestock and wildlife.

Wildflowers and Herbs

Some herbaceous plants and wildflowers are found in riparian areas, adding color and diversity to the landscape [43].

Shrubbery and understory plants

In addition to trees and grasses, shrubs and understory plants such as various species of *Haloxylon* and *Artemisia* are also present in riparian zones.

Wetlands and Marshes

In some riparian areas with consistent water flow, small wetlands or marshes form, supporting a unique suite of wetland plants, such as sedges, bulrushes, and aquatic plants.

Challenges

Ladakh region presents unique challenges to biodiversity due to its extreme environmental conditions and human activities [18]. The key challenges to biodiversity in Ladakh include the following:

Changes in land use

Land use changes in Ladakh have significant impacts on biodiversity. Ladakh is a high-altitude desert region with unique and fragile ecosystems. Therefore, any alterations to the land can disrupt the delicate balance of its biodiversity [50]. The factors influencing land use change are responsible for inducing biodiversity in Ladakh are as follows:

Urbanization and Infrastructure Development

After the elevation of the administrative status of Ladakh as a Union Territory, the pace of urbanization and infrastructure development, which involved clearing land for roads, buildings, and other structures, increased manyfold. This can lead to habitat loss for various species in the long run, especially those adapted to high-altitude desert environments.

Agriculture

Ladakh has traditionally been an agrarian society, but modern agricultural practices can have consequences. The expansion of agricultural land often results in the clearing of natural habitats that harm local flora and fauna.

Soil erosion, land degradation and desertification landscape

The topography is rugged, sloping, and undulating, which makes the region highly prone to soil erosion. Soil erosion peaks due to the melting of snow during the summer season. This results in the removal of the top fertile soil from agricultural lands. Approximately 24% area of the district is degraded by wind and water [11]. About 58% of the area is in the sandy/rocky/wasteland use category whereas 11% of the area is covered by snow and glaciers. Due to poor soil profile development, the soils of the Ladakh region vary not only in their morphological and physico-chemical properties but also in their genesis. There is clear evidence of increasing desertification in this trans-Himalayan region.

Tourism

Ladakh has become a popular tourist destination. While tourism provides economic benefits, it has also put pressure on the environment. A heavy inflow of tourists leads to overdevelopment, waste disposal issues, and disturbances to wildlife (Figure 5).

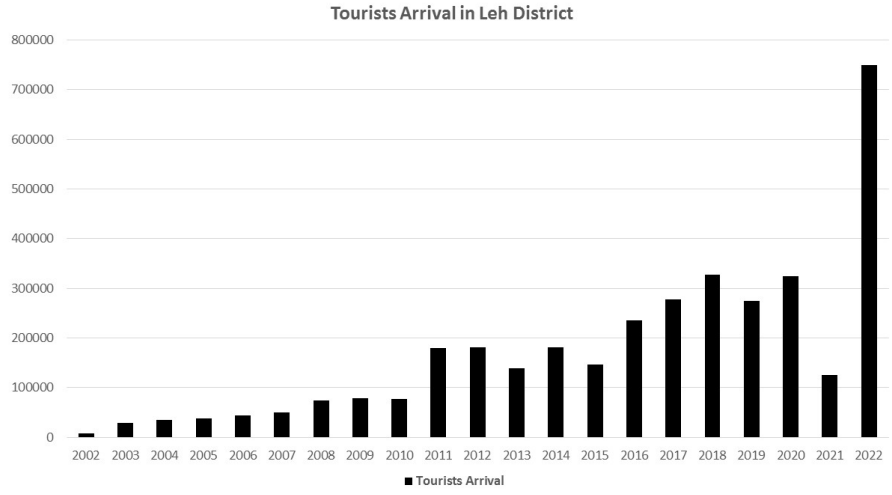

Figure 5. *The influx of tourists in Leh District (2002 - 2022)*

Climate Change

Land use changes exacerbate the effects of climate change. For example, deforestation or changes in land cover can alter local microclimates, affecting the distribution of plant and animal species. This can lead to shifts in the composition of Ladakh's biodiversity. Additionally, factors such as glacial retreat and altered precipitation patterns can indirectly contribute to habitat loss in Ladakh. As glaciers recede, they may affect the availability of meltwater and influence the distribution of certain species.

Traditional Practices

Traditional land use practices of Ladakhi communities, such as transhumance (seasonal movement of livestock), have coexisted with local ecosystems for centuries. However, changes in these practices, such as the abandonment of certain agricultural terraces or nomadic routes, can affect both habitat and biodiversity.

Harsh Climate

Ladakh experiences extremely cold and arid conditions, with low temperatures and limited rainfall. These harsh climatic conditions make it challenging for many species to survive and thrive.

Extreme cold

Ladakh experiences extremely cold temperatures, especially in the winter months. During the winter, temperatures can plummet well below freezing, often reaching as low as -40°C or even lower in some areas. Cold weather poses challenges for agriculture, transportation, and human habitation.

Limited precipitation

Ladakh is situated in the rain shadow of the Himalayan Mountains, which means that it receives very little rainfall. The annual precipitation is typically less than 100 millimeters (4 inches), and the region relies heavily on snowmelt for its water supply [11]. This arid climate limits the availability of water for both people and wildlife.

Short growing season

Due to extreme cold and limited precipitation, Ladakh has a short growing season. Agriculture is challenging, and traditional farming practices involve growing cold-resistant crops such as barley, wheat, and some leafy and cruciferous vegetables in open conditions on limited land during the summer months.

Harsh Terrain

Ladakh's rugged and mountainous terrain, combined with the harsh climate, makes it a challenging environment for both human settlement and wildlife survival. The steep slopes and rocky landscapes of these areas limit agricultural opportunities and habitats for many species.

Habitat loss

Human activities such as agriculture, urbanization, and infrastructure development have led to habitat loss in Ladakh. The construction of roads, buildings, and other infrastructure can fragment and destroy natural habitats, reducing the available space for wildlife. Several factors contribute to habitat loss in Ladakh:

Urbanization and Infrastructure Development

The expansion of towns and cities in Ladakh often leads to the conversion of natural habitats into built-up areas. As the population grows and demands for housing, roads, and commercial spaces increase, natural landscapes, including grasslands and wetlands, are being transformed or lost.

Agricultural Expansion

Agriculture is a vital economic activity in Ladakh, but it can also contribute to habitat loss. As farmers seek to cultivate more land to meet the region's food needs, they may clear natural vegetation, which can fragment habitats and reduce the availability of food and shelter for wildlife [11].

Grazing Pressure

Livestock grazing, particularly by goats, sheep, and yaks, is a common practice in Ladakh. Overgrazing can lead to the degradation of grasslands and other vegetation, impacting both the plant and animal species that depend on these habitats [11].

Mining and Quarrying

The extraction of minerals, sand, and stones for construction and industrial purposes can disrupt natural landscapes and habitats. Soil compaction can lead to soil erosion, loss of vegetation, and disturbances to local ecosystems.

Tourism

Ladakh has become a popular tourist destination, attracting visitors worldwide. While tourism can bring economic benefits, it can also have negative impacts on the environment. The construction of hotels, guesthouses, and other infrastructure to accommodate tourists can encroach on natural areas [11].

Hydroelectric Projects

The development of hydroelectric projects in the region can alter riverine ecosystems and disrupt habitats. The construction of dams and reservoirs can flood areas that were once home to diverse aquatic species.

Invasive species

The introduction of non-native species, whether intentionally or accidentally, can disrupt local ecosystems and displace native species. Invasive species may thrive in altered habitats and compete with native flora and fauna.

Grazing pressure

Livestock grazing is a common practice in Ladakh, and overgrazing can lead to the degradation of grasslands and other habitats. This can harm the vegetation and the species that depend on it. Grazing pressure, primarily from livestock such as goats, sheep, yaks, and cattle, is a significant factor contributing to biodiversity loss in Ladakh, a region in northern India [11,18]. There are several ways in which grazing pressure can impact biodiversity in Ladakh:

Habitat Degradation

Intense grazing can lead to the degradation of natural habitats, including grasslands, shrublands, and wetlands. Overgrazing removes vegetation, disrupts soil structure, and can lead to soil erosion. As a result, the quality and availability of food and shelter for native wildlife are compromised.

Soil erosion

Grazing can exacerbate soil erosion in fragile high-altitude ecosystems of Ladakh. The removal of vegetation by livestock reduces the stabilizing effect of plants on the soil, increasing susceptibility to erosion by wind and water. Soil erosion can lead to the loss of fertile topsoil and negatively impact plants and animal species dependent on stable soils.

Trampling and Habitat Fragmentation

Grazing animals can trample sensitive habitats, including wetlands and riparian areas, which are critical for various species. Trampling can damage plant communities and disrupt

aquatic ecosystems. Additionally, livestock trails and pathways can fragment habitats, making it more challenging for wildlife to access resources and migrate [51].

Altered Vegetation Composition

Continuous grazing can alter the composition of plant species in an area. Grazing-resistant species may dominate while more palatable and native vegetation may decline. This can have cascading effects on other species that depend on specific plant species for food and habitat.

Soil nutrient depletion

Overgrazing can lead to soil nutrient depletion, increasing the difficulty of plant growth and regeneration. This can further reduce the carrying capacity of the land and negatively impact the overall health of the ecosystem [11].

Human-Wildlife Conflict

As human populations expand and encroach on wildlife habitats, conflicts between humans and wildlife, particularly large carnivores such as snow leopards and wolves, can occur. These conflicts often result in retaliatory killing of these animals. Human-wildlife conflict is a significant issue in Ladakh, where human communities coexist with a variety of wildlife species, including snow leopards, wolves, ibex, and yaks. This conflict arises when there are clashes between the needs and activities of humans and the presence and behavior of wildlife [4,44]. Human-wildlife conflict can have several negative impacts on biodiversity in Ladakh:

Predation on Livestock

Large carnivores such as snow leopards and wolves often prey on domestic livestock, including goats, sheep, and yaks. This predation can lead to economic losses for herders and create tensions between humans and wildlife. In response, herders may retaliate by killing these predators, leading to a decline in their population.

Livestock grazing

Grazing by domestic livestock can negatively impact the vegetation and habitats on which native wildlife depend. Overgrazing can lead to habitat degradation, reduced food availability for wildlife, and competition for resources.

Competition with Wildlife

Livestock often compete with native wildlife for limited forage resources. This competition can place additional stress on plants and lead to reduced food availability for native herbivores, such as the Tibetan wild ass (kiang) and blue sheep (*bharal*). This can impact the health and survival of these species over time.

Crop Damage

Wildlife plants, particularly herbivores such as blue sheep (*bharal*) and marmots, can cause damage to crops. This can lead to conflicts as farmers seek to protect their livelihoods and food sources.

Human Safety Concerns

In some cases, encounters with large carnivores such as snow leopards can pose a safety risk to humans. Fear of attack or livestock loss can result in retaliatory killing of these predators.

Habitat fragmentation

Human-wildlife conflict can lead to habitat fragmentation as a result of infrastructure development (e.g., fences) erected to protect crops or livestock. Fragmentation can disrupt wildlife movement and lead to the isolation of populations, which can increase vulnerability to genetic issues and reduce biodiversity.

Addressing the challenges

There is an urgent need to address these challenges and mitigate them to protect the biodiversity of the Ladakh region; thus, the following strategies can be employed:

Land use changes

Several measures need to be taken to mitigate the negative impacts of land use changes on biodiversity in Ladakh:

Sustainable Development

Sustainable development practices that consider the region's unique ecology should be encouraged. This may involve zoning regulations, habitat conservation, and sustainable tourism management [51].

Habitat Protection

Identify and protect critical habitats and corridors for wildlife. Establishing protected areas and wildlife sanctuaries can help conserve biodiversity.

Land-Use Planning

Implementing zoning and land-use regulations that prioritize conservation can help balance development with the protection of natural habitats.

Community Engagement

Involve local communities in conservation efforts and promote traditional and sustainable land use practices that coexist with biodiversity.

Education and Awareness

Raise awareness among tourists, residents, and policymakers about the importance of biodiversity conservation and the consequences of unsustainable land use.

In Ladakh, as in many other regions, a balance must be struck between development and biodiversity conservation to ensure the long-term sustainability of both the natural environment and well-being of the local communities.

Habitat Loss

Efforts to address habitat loss in Ladakh often involve a combination of conservation strategies, including the following:

Establishing Protected Areas

Creating and effectively managing protected areas and wildlife reserves can help safeguard critical habitats for native species.

Habitat Restoration

Initiatives to restoring degraded habitats through reforestation, afforestation, and grassland management can help revitalize ecosystems.

Public Awareness and Education

Raising awareness among local communities and tourists about the importance of biodiversity and responsible land use can foster a culture of conservation [11].

Efforts to mitigate habitat loss in Ladakh require collaboration among government agencies, conservation organizations, local communities, and other stakeholders to strike a balance between development and environmental preservation.

Grazing Pressure

Efforts to mitigate the negative impacts of grazing pressure on biodiversity in Ladakh may be involved [2]:

Implementing Grazing Management Plans

Sustainable grazing management plans can be developed to ensure that livestock grazing is carried out in a way that minimizes habitat degradation and allows vegetation to recover [51].

Rotational Grazing

Implementing rotational grazing practices can help prevent overgrazing in specific areas by helping livestock move to different pastures at different times.

Fencing

Installing fences or enclosures to protect sensitive habitats or critical wildlife areas from livestock access can help preserve these areas.

Increasing fodder and pasture potential

Improving the productivity of fodder in farmerss' fields as well as increasing pasture production capacity by creating irrigation facilities in fenced areas to reduce grazing pressure

Educating Herders

Providing education and training about sustainable grazing practices and the importance of biodiversity conservation can promote more responsible livestock management [2].

Balancing the needs of livestock-dependent communities with biodiversity conservation efforts is crucial in addressing grazing pressure-related challenges in Ladakh and ensuring the long-term sustainability of the region's unique ecosystems [2,50].

Invasive species

Management and control of invasive species in Ladakh require a combination of strategies, including the following:

Prevention

Implementing measures to prevent the introduction of new invasive species through human activities, such as trade and tourism.

Early Detection and Monitoring

Developing systems to detect and monitor invasive species in the region, allowing for prompt action.

Control Measures

Control measures, such as removal, containment, and eradication efforts, should be implemented when invasive species are identified.

Research

Conduct research to understand the ecological impacts of invasive species and develop effective control strategies.

As in other regions, efforts to address invasive species in Ladakh, require collaboration among government agencies, conservation organizations, researchers, and local communities to protect and preserve the region's unique biodiversity and ecosystems.

Climate Change

To address these challenges and mitigate the impact of climate change on biodiversity in Ladakh, the following strategies can be employed:

Conservation Planning

Developing and implementing conservation plans that take into account the changing climate and the specific vulnerabilities of species and habitats in Ladakh [11].

Monitoring and Research

Continuously monitoring the impacts of climate change on Ladakh's biodiversity and researching this subject matter to understand the adaptive responses of the species are essential.

Policy and Regulation

Implementing policies and regulations that promote sustainable land use, reduce greenhouse gas emissions, and protect vulnerable ecosystems [11].

Given the fragile and unique nature of Ladakh's ecosystems, proactive efforts to address climate change impacts are essential to ensure the long-term survival of its biodiversity and the well-being of its inhabitants.

Pollution

Mitigating the impact of pollution on biodiversity in Ladakh requires a multi-pronged approach:

Waste Management

Implementing effective waste management practices, including recycling and proper disposal, can reduce litter and contamination in natural habitats.

Clean Energy

Promoting clean and sustainable energy sources can help reduce air pollution from fossil fuels.

Environmental Education

Raising awareness among local communities and tourists about the importance of preserving Ladakh's pristine environment and biodiversity can foster responsible behavior [29].

Regulation and Enforcement

Implementing and enforcing environmental regulations and pollution control measures can help reduce pollution levels.

Sustainable Tourism

Sustainably managing tourism, including limiting the impact of infrastructure development and visitor activities, can help minimize pollution in tourist hotspots.

Addressing pollution in Ladakh is vital for protecting its unique biodiversity, supporting local communities, and ensuring the long-term ecological health of the region. Collaboration between government agencies, conservation organizations, local communities, and visitors is crucial in tackling this issue effectively.

Human-Wildlife Conflict

Efforts to address human-wildlife conflict in Ladakh while minimizing its impact on biodiversity include the following:

Community-Based Conservation

Involving local communities in conservation efforts, including compensation programs for livestock losses and the implementation of predator-proof livestock enclosures, can help mitigate conflicts.

Education and Awareness

Raising awareness among local communities about the ecological importance of wildlife and the benefits of coexistence can reduce retaliatory killings.

Research and Monitoring

Understanding the behavior and movement patterns of wildlife species can help inform conservation strategies and reduce conflicts. Tools such as GPS collaring can provide valuable data.

Alternative Livelihoods

Promoting alternative livelihoods and income sources, such as ecotourism or nonlivestock-based livelihoods, can reduce dependence on vulnerable livestock and mitigate conflicts [11].

Protected areas and corridors

Designating and effectively managing protected areas and wildlife corridors can help maintain habitat connectivity and

provide safe passages for wildlife, reducing conflicts with humans.

Coordinated Management

Collaboration between government agencies, conservation organizations, and local communities is crucial for implementing effective strategies to address human-wildlife conflicts while safeguarding biodiversity.

Balancing the needs of human communities with the conservation of Ladakh's unique biodiversity is a complex challenge. Effective management and conflict resolution efforts can help minimize the negative impacts of human-wildlife conflict on biodiversity and ensure the long-term survival of both wildlife and local livelihoods [11].

Conclusion

Ladakh's vegetation is adapted to the harsh climatic conditions of high altitudes, extreme cold, and limited precipitation. Plants have developed special adaptations, such as reduced leaf size to minimize water loss and the ability to withstand freezing temperatures [11]. The region's flora include species such as wild roses, sea buckthorn, thorny shrubs, and several medicinal herbs.

Human activities, such as grazing and agriculture, have also influenced the vegetation patterns in Ladakh [2,11]. Traditional agricultural practices like terraced farming and artificial irrigation have allowed for the cultivation of barley, wheat, and other crops in valleys. It is important to note that Ladakh's environment is fragile, and climate change is posing new challenges to its unique phytogeography. Increased temperatures and changing precipitation patterns can have significant impacts on a region's ecosystems and biodiversity. Conservation efforts are underway to protect the delicate balance of flora and fauna in this high-altitude desert region [11]. Conservation organizations, government agencies, and local communities are working together to protect and sustainably manage the region's natural resources. These efforts include the establishment of protected areas, habitat restoration initiatives, and community-based conservation programs. The remote and challenging terrain of Ladakh has limited the amount of research and conservation efforts in the region. This lack of information and resources can hinder effective conservation strategies.

Acknowledgment

The authors are grateful to the Technical Staff of the Regional Research Station, ICAR-Central Arid Zone Research Institute, Stakna, Leh for their support and help in conducting field surveys.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Availability of data

The complete dataset produced or examined during the study has been incorporated into the referenced articles and is duly acknowledged in the reference section.

Funding Sources

No funding was received from any source to conduct this study.

Authorship

MKG, and MSK made substantial contributions to the study through conception and design; data acquisition,; MKG, VC and NS organized and contributed to fiework, MKG, MSK and ARC did analysis and interpretation of data; MKG, MSK, VC, RKG and ARC were involved in drafting the manuscript; MSK, VC, RKG & NS helped revising it critically for important intellectual content. All the authors have given final approval for the version to be published. All the authors agree to be accountable for all the aspects of the work involved in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. *Singh DK, Hajra K. Floristic diversity. In: Gujral GS, Sharma V, eds. Changing Perspectives of Biodiversity Status in the Himalayas. New Delhi, India: British Counsel Division; 1996:23-38.*
2. *Rawat GS, Adhikari BS. Vegetation characteristics and patterns of livestock grazing in Changthang plateau, eastern Ladakh. Report submitted to International Centre for Integrated Mountain Development, Kathmandu, Nepal, and Wildlife Institute of India, Dehra Dun, Uttaranchal; 2002. 26pp.*
3. *Dovrsky M, Klimes L, Dolezal J, Wild J, Dickore W. A Field Guide to the Flora of Ladakh. Praha, Czech Republic: Academia; 2018:291.*
4. *Fox JL, Nurbu C, Bhat S, Chandola A. Wildlife conservation and land use changes in the Trans-Himalayan region of Ladakh, India. Mountain Research and Development. 1994;14(10):39-60.*
5. *Dolezal J, Dovrsky M, Borner A, Wild J, Schweingruber FH. Anatomy, Age and Ecology of High Mountain Plants in Ladakh, the Western Himalaya. Switzerland: Springer International Publishing; 2018.*
6. *Dhar U, Rawal RS, Upreti J. Setting priorities for conservation of medicinal plants – a case study in the Indian Himalaya. Biological Conservation. 2000;95:57-65.*
7. *Miehe G, Miehe S, Dickore WB. Alpine deserts in high Asia. In: Xiaping Y, ed. Desert and Alpine Environments – Advances in Geomorphology and Palaeoclimatology. China: China Ocean Press; 2002:59-79.*
8. *Singh N, et al. Dataset on mapping and morphometry of sand dunes in Nubra and Shyok valleys, Ladakh Himalaya, India. Indian Journal of Scientific Research. 2019;10(1):11-19.*
9. *Murugan MP, Raj J, Kumar GP, Gupta GS, Singh SB. Phytofoods of Nubra valley, Ladakh – The cold desert. Indian Journal of Traditional Knowledge. 2010;9:303-308.*
10. *Dorjey K. Exploration of plant based traditional knowledge from Sham region of Ladakh (J&K), India. Journal of Plant Development Sciences. 2015;7(5):429-433.*
11. *Gaur MK. Land use changes, agricultural productivity and food security in cold arid ecosystem of Ladakh, India. Keynote presentation in National Conference on Desert Ecosystems: Status, Emerging Challenges and Perspectives. Jointly organised by Centre for Environment and Development Studies, Jaipur and Indian Society for Agricultural Economics; November 15-16, 2022.*
12. *Stewart RR. Flora of Ladakh, Western Tibet. Dehradun, India: Bishen Singh Mahendra Pal Singh; 2003.*
13. *Gaur MK, Goyal RK, Chaudhary V. Sea buckthorn (Hippophae spp. L): A Sanjeevani (elixir) of cold arid Trans-Himalayan region of India. Journal of Namibian Studies. 2023;35(S1):3394-3412. doi:10.59670/jns.v35i.4235*
14. *Singh N, Gaur MK. Morphology and migration of sand dunes in Nubra and Shyok valleys, Ladakh, India. In: Qi L, Gaur MK, Squires VR, eds. Sand Dunes of the Northern Hemisphere: Distribution, Formation, Migration and Management. Vol. 1. CRC Press; 2022:315-324.*
15. *Humbert-Droz B, Dawa S, eds. Biodiversity of Ladakh: Strategy*

and Action Plan. New Delhi, India: Sampark; 2004.
16. *Joshi PK, Rawat GS, Padilya H, Roy PS. Biodiversity characterization in Nubra Valley, Ladakh with special reference to plant resource conservation and bioprospecting. Biodiversity and Conservation. 2006;15:4253-4270.*
17. *Hartmann H. A summarizing report on the phytosociological and floristical explorations (1976-1997) in Ladakh (India). Unpublished work; 2009.*
18. *Stork NE, Samways MJ, Eeley HAC. Inventorying and monitoring biodiversity. Trends in Ecology and Evolution. 1996;11:39-40.*
19. *Gaur MK. Prospects of biodiversity in Trans-Himalayan region of Ladakh, India. Keynote lecture in International Conference on Himalayan Environments in Changing Climate Scenario, organized by the University of Ladakh, Leh; September 19-23, 2023.*
20. *Kachroo P. Plant diversity in Northwest Himalaya: A preliminary survey. In: Dhar U, ed. Himalayan Biodiversity. Conservation Strategies. Nainital, India: Gyanodaya Prakashan; 1993:111-132.*
21. *Kumar GP, Kumar R, Chaurasia OP. Conservation status of medicinal plants in Ladakh: Cold arid zone of Trans-Himalayas. Research Journal of Medicinal Plant. 2011;5:685-694.*
22. *Klimes˘ L, Dolezal J. An experimental assessment of the upper elevational limit of flowering plants in the western Himalaya. Ecography. 2010;33:590-596.*
23. *Dovrsky M, Dolezal J, de Bello F, Klimesova J, Klimes J. Vegetation types of East Ladakh: Species and growth form composition along main environmental gradients. Applied Vegetation Science. 2010;14:132-147.*
24. *Gaur MK, Goyal RK, Saha D, et al. The estimation of snow cover distribution using satellite data in the cold arid Leh region of Indian Himalaya. Polish Journal of Environmental Studies. 2022;31(1):63-73.*
25. *Chaurasia OP, Ahmed Z, Ballabh B. Ethnobotany & Plants of Trans-Himalaya. New Delhi, India: Satish Serial Publishing House; 2007.*
26. *Pfister, Otto. Birds and Mammals of Ladakh. Oxford University Press. 2004; 450.*
27. *Mandal RB. Land utilization: Theory and Practice. Concept Publishing Company: New Delhi. 1990.*
28. *Gaur MK, Goyal RK, Kumar M. Mapping of Decadal Changes in Land Degradation Status for Jalor District. CAZRI News. 2021; 11(2):2-3.*
29. *Gaur MK, Goyal RK. Landslide geohazards in Trans-Himalayan region of Ladakh. The Earth News. August 30, 2023:5.*
30. *Nusser M, Dickore WB. A tangle in the triangle: Vegetation map of the eastern Hindukush (Chitral, Northern Pakistan). Erdkunde. 2002;56(1):37-59.*
31. *Kachroo P, Sapru BL, Dhar U. Flora of Ladakh: An Ecological and Taxonomical Appraisal. Dehradun, India: Bishen Singh Mahendra Pal Singh; 1997.*
32. *Rawat GS, Adhikari BS. Floristics and distribution of plant communities across moisture and topographic gradients in Tso Kar basin, Changthang plateau, eastern Ladakh. Arctic, Antarctic and Alpine Research. 2005;37:539-544.*
33. *Stewart JIL. Notes of a botanical tour in Ladak or Western Tibet. Transactions of the Botanical Society of Edinburgh. 1870;10(1/4):207-239.*
34. *Klimes˘ L, Dickore´ WB. Flora of Ladakh (Jammu & Kashmir, India). A preliminary checklist. Published 2006. Accessed July 17, 2024. http://www.butbn.cas.cz/klimes*
35. *Chaurasia OP, Khatoon N, Singh SB. Field Guide: Floral Diversity of Ladakh. World Wide Fund for Nature-India (J&K, Ladakh) & Defence Institute of Higher Altitude Research, Leh-Ladakh; 2008.*
36. *Dorjey K, Dolma P. Plants of Ladakh: A Photographic Guide. Mysore, India: Nature Conservancy Foundation-India; 2021:252.*
37. *Kala CP. Floral diversity and distribution in the high altitude cold desert of Ladakh, India. Journal of Sustainable Forestry. 2011;30(5):360-369.*
38. *Dorjey K, Tamchos S, Kumar S. Ethnobotanical observations in Trans-Himalayan region of Ladakh. Journal of Plant Development Sciences. 2012;4(4):459-464.*
39. *Chaurasia OP, Singh B. Cold Desert Plants. Vol. I-IV. Leh, India: Field Research Laboratory, DRDO; 1996.*
40. *Murty SK. Flora of Cold Deserts of Western Himalaya. Vol. 1. (Monocotyledons). Dehradun, India: Botanical Survey of India; 2001.*
41. *Raina AK, Hamid A. Floristic analysis of Chiktan Valley in Kargil district, Jammu and Kashmir. Environment Conservation Journal. 2014;15(3):71-79.*
42. *Singh RP, Gupta MK. Studies on biomass, fodder value, coppicing ability and energy contents of Debregeasia hypoleuca Weld in Western Himalayas. The Indian Forester. 1990;116:780-785.*
43. *Polunin O, Stainton A. Concise Flowers of the Himalaya. New Delhi, India: Oxford University Press; 1987:283.*
44. *Hamid A, Raina AK. Ethnobotanical uses of plants in and around Kanji Wildlife Sanctuary, North West Himalaya. International Journal of Science and Research. 2014;3(11):538-545.*
45. *Baldock K, Smith N. A study of plant diversity along an altitudinal gradient in the Nubra Valley region in Ladakh. BSES Expeditions Ladakh 2009. Science Report Ecology. Published 2019. Accessed July 17, 2024. https://bristol.academia.edu/KatherineBaldock*
46. *Kumar GP, Gupta S, Murugan PM, Singh SB. Ethnobotanical studies of Nubra Valley-a cold arid zone of Himalaya. Ethnobotanical Leaflets. 2009;13:752-765.*
47. *Ballabh B, Chaurasia OP. Traditional medicinal plants of cold desert Ladakh – used in treatment of cold, cough and fever. Journal of Ethnopharmacology. 2007;112:341-349.*
48. *Gairola S, Sharma J, Bedi YS. A cross-cultural analysis of Jammu, Kashmir and Ladakh (India) medicinal plant use. Journal of Ethnopharmacology. 2014;155(2):925-986.*
49. *Kumar J, Rai H, Khare R, Upreti DK, Dhar P, Tayade AB, Chaurasia OP, Srivastava RB. Elevational controls of lichen communities in Zanskar valley, Ladakh, a Trans-Himalayan cold desert. Tropical Plant Research. 2014;1(2):48-54.*
50. *Gaur MK, Squires VR. Changes in agricultural land use and food security: Challenges and opportunities for western drylands of India. In: Squires VR, Gaur MK, eds. Food Security and Land Use Change under Conditions of Climate Variability: A Multidimensional Perspective. Springer; 2020:257-280.*
51. *Squires VR, Gaur MK. Food security and land use change under conditions of climate variability: Synthesis and uniting perspectives. In: Squires VR, Gaur MK, eds. Food Security and Land Use Change under Conditions of Climate Variability: A Multidimensional Perspective. Springer; 2020.*