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Assessment of livestock carrying capacity in the alpine grasslands of the Kashmir Himalayas

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The alpine grasslands of the Kashmir Himalayas serve as a lifeline for the region's pastoral communities, providing the primary source of forage for their livestock. These high-altitude rangelands are not only crucial for the livelihood of these communities but also play a significant role in maintaining the ecological balance of the area. However, sustainable pastoralism in these fragile ecosystem hinges on a thorough understanding of forage availability and livestock carrying capacity. This study assesses the forage dynamics and livestock carrying capacity of these high-altitude grasslands. Through comprehensive biomass sampling across 23 strategically selected sites, we calculated an average dry matter above ground biomass yield of 5.10 metric tons per hectare, resulting in a total dry biomass weight of approximately 820,489.22 metric tons (820,489,220 kg), over the entire grassland area of 160,974 ha. Using a daily forage intake of 1.3 kg per Sheep Unit (SU) over 50 grazing days, time period which corresponds to the renewal period for new grass growth, the average carrying capacity of the rangelands was determined to be 39.08 Animal Units (AU) per hectare and the total carrying capacity was estimated as 62,78,556 SU. The current stocking rate of 4,661,800 SU utilizes about 74.21% of this Carrying capacity, leaving a surplus of 25.77% or 1,616,756 Animal Sheep Units. However, localized overgrazing in areas such as Thajwas and Mohand Marg highlights the need for targeted management practices to prevent rangeland degradation. This data is critical as it provides a baseline for understanding the potential of these rangelands to support livestock. This study underscores the importance of sustainable livestock management to optimize carrying capacity while maintaining the ecological balance of the grasslands. Engaging local pastoral communities in these efforts is essential for the effective and sustainable management of the alpine grasslands in the Kashmir Himalayas.

KEYWORDS

forage availability, carrying capacity, Kashmir Himalayas, pastoralism, alpine grasslands

Introduction

Grasslands cover around 40% of terrestrial ecosystems, accounting for 3,500 million hectares on Earth, and are vital for energy transmission, global biogeochemical cycles, and climate change dynamics (Scurlock and Hall, 1998; Piao et al., 2004; FAO, 2018, 2019). Rangelands, one of the largest ecosystems on the planet, are vital for biodiversity and the livelihoods of millions of people, particularly pastoral communities. Grasslands are integral not only for livestock sustenance but also for providing essential ecosystem services such as carbon sequestration, water regulation, and biodiversity conservation (DeFries and Rosenzweig, 2010; Xu et al., 2013; Fassnacht et al., 2015). However, overgrazing has long been recognized as a critical factor contributing to rangeland degradation (Akiyama and Kawamura, 2007). Grazing pressure, if not properly managed, can lead to reduced vegetation cover, soil compaction, and changes in plant species composition, all of which compromise the health and productivity of rangelands (Milchunas and Lauenroth, 1993). Global discussions on rangeland management underscore the importance of balanced grazing practices to prevent long-term ecosystem damage (Briske D. D. et al., 2015). Moderate grazing can enhance ecosystem resilience, while overgrazing diminishes rangelands' regenerative capacity, leading to biodiversity loss (Oesterheld et al., 1992; Holechek, 1988). Nonetheless, rangelands remain susceptible to degradation, primarily due to overgrazing. The rapid population growth over recent decades has led to increased demand for natural resources and animal products, exerting immense pressure on grassland ecosystems and causing severe degradation (Zhou et al., 2003). Recognizing the importance of grasslands in sustainable intensification, there is a growing emphasis on improving productivity and efficiency within these ecosystems (Zhou et al., 2005; Bogaerts et al., 2017; Palermo et al., 2014; Thornton and Herrero, 2010). Accurate modeling and prediction of the spatial and temporal dynamics of grassland ecosystems are essential for their conservation and sustainable management (Li et al., 2016; Cao et al., 2019). Grassland degradation has led to a decline in the carrying capacity per hectare regarding grass consumption (Golluscio et al., 2015). To mitigate this degradation and promote sustainable grazing practices, comprehensive studies on the current state of grasslands, considering both spatial and temporal dimensions, are imperative. Fodder yield, a key indicator of grassland health and a determinant of animal carrying capacity, necessitates careful evaluation (Holecheck, 1988; Hunt et al., 2003; Hunt and Miyake, 2006).

Livestock carrying capacity refers to the maximum number of livestock units that a particular area of grassland can support without causing environmental degradation. This concept is crucial for sustainable grassland management as it ensures that grazing does not exceed the regenerative capacity of the ecosystem (Dong et al., 2022) Overgrazing, which occurs when livestock density surpasses the carrying capacity, can lead to soil erosion, loss of plant species, and a decrease in biomass productivity, thereby further diminishing the carrying capacity over time (Fuhlendorf and Engle, 2001). Effective management strategies must incorporate regular assessments of carrying capacity to adaptively manage grazing pressure and maintain ecosystem health (Teague et al., 2013).

The alpine grasslands of the Kashmir Himalayas are crucial for the livelihoods of local pastoral communities and the region's ecological stability. The degradation of these ecosystems is particularly detrimental for over 1,000 species in the alpine regions of the Himalayas, significantly reducing their survival chances (Rawat, 2005; Körner et al., 2006). The tradition of animal husbandry in Kashmir's natural grasslands spans nearly a millennium, with grazing being the primary human activity shaping these grassland communities (Singh et al., 2018). Overgrazing has led to ecological degradation, severely impacting the sustainable development of animal husbandry in these grasslands (Hua and Squires, 2015; Briske D. D. et al., 2015; Tong et al., 2004; Yu et al., 2004). Variations in grassland composition and biomass production across landscapes are influenced by factors such as terrain, biotic stresses, species dominance, rainfall patterns, and plant species' successional status (Liu et al., 2019). However, over the past century, insufficient attention has been given to balancing ecological preservation with production functions in Kashmir's grasslands (Roy and Singh, 2013). While traditional field-based studies have been conducted on grasslands in some regions, there is a pressing need for more comprehensive examinations in other areas to develop effective pasture lands management strategies (Rawat, 1998; Saleem et al., 2019). Traditional practices and scientific assessments can work together to sustain livestock populations and protect grasslands. In this study, aboveground biomass (AGB) was estimated using the plot field harvest method, which is considered the most accurate and reliable approach for determining biomass (Meng et al., 2022). Area under grassland use type was calculated using supervised land use classification (Saleem et al., 2021; Mushtaq et al., 2024; Saleem et al., 2024), to estimate the total area of grasslands the alpine and sub-alpine regions were delineated first, ensuring more accurate results.

This study on forage availability and livestock carrying capacity is vital to optimize livestock numbers, prevent ecological degradation, and support sustainable pastoral practices. Understanding forage dynamics informs policy-making for effective rangeland management. Engaging local communities fosters sustainable grazing practices, integrating traditional knowledge with scientific insights (Biró et al., 2019; Sharifian et al., 2022). Ultimately, this study provides a framework for the long-term sustainability of the grasslands, ensuring economic stability and ecological health for future generations.

Materials and methods

Study area

The Kashmir Himalayas, located in the northwestern part of the Indian subcontinent, are distinguished by their complex and diverse geographical and ecological landscape. This region extends roughly from 32°22′ to 34°43′ N latitude and 73°52′ to 75°42′ E longitude, bordered by the Great Himalayas to the northeast and the Pir Panjal Range to the southwest. The Kashmir Valley, a notable feature of this region, is an elliptical, bowl-shaped valley approximately 135 km long and up to 40 km wide, situated at altitudes ranging from 1,600 m to 5,375 m above sea level (Saleem et al., 2021). The Jhelum River, which cuts through the Pir Panjal range at the Baramulla gap, predominantly drains this valley. The region experiences a varied climate, with cold winters and moderate summers. The ecological and environmental diversity of the Kashmir Himalayas is notable, the region hosts numerous glaciers. The Kashmir Himalayas are also home to extensive alpine grasslands (Figure 2), which are a critical component of the region's biodiversity. These grasslands support a variety of flora and fauna, including several species of grasses, herbs, and medicinal plants. Some notable varieties found in these grasslands include the endemic Himalayan blue poppy (*Meconopsis aculeata*), *Saussurea obvallata,* and numerous species of *Rhododendron,* notable plant genera in these grasslands include *Aconitum, Gentiana, Iris, Pedicularis, Potentilla*, *Primula*, and *Ranunculus*, while *Astragalus, Lotus, Medicago*, and *Trifolium* are prominent legumes as documented by (Dad and Khan, 2010; Zargar, and Shah, 2012). These alpine ecosystems are not only important for biodiversity conservation but also for the livelihoods of local communities who depend on these grasslands for grazing livestock and harvesting medicinal plants.

Land use land cover generation

The study utilized Landsat 8 OLI Surface reflectance having a 30-m resolution acquired using cloud filtering from the USGS database and subsequently pre-processed. Prior to land use classification, to accurately relate the gathered data to biophysical phenomena (Saleem et al., 2024), the acquired satellite imagery was geo-referenced and rectified to fit the UTM zone 43 N, adhering to the WGS84 datum. Following the assessment of data quality, the imagery was processed using ERDAS Imagine 9.1 for radiometric and geometric corrections, such as image enhancement, layer stacking, mosaicking (Chander and Markham, 2003), and sub-setting according to the study area. The Land Use Land Cover (LULC) analysis was carried out, focusing on the alpine and sub-alpine regions of Kashmir. The classification process identified six distinct LULC classes, including Open Forest, Exposed Rock, Forest, Shrubland, Grasslands, and Snow-covered region. Among the various available LULC classification techniques, area under different landuse classes were determined by using the maximum likelihood classifier algorithm to generate accurate and reliable LULC map. Figure 1 provides a visual representation of the methods employed in this study.

Herbaceous plant sampling

To collect aboveground biomass data, herbaceous plant samples were collected using the direct field plot harvest technique from alpine and sub-alpine region of Kashmir above 2,500 m. The dry biomass was measured by oven-drying collected samples at 105°C for 72 h until a constant weight was achieved. This process ensured the complete removal of moisture content, allowing for an accurate calculation of the dry biomass available in each pasture lands. A total of 92 field observations were conducted over the period of 2 years from 2021 to 2022. Four 1 m^2 (1 m × 1 m) quadrants (Mueller et al., 1974; Kent and Coker, 1992), were laid down per site, two from grazed areas near their wooden huts where they stay and two from the ungrazed area of pasture lands and all herbaceous plant species were harvested from above ground. Figure 2 displays the location of sampling sites, which were selected to ensure the representation of all major grasslands across the study region.

Carrying capacity estimation

The concept of carrying capacity (CC) in the context of rangelands pertains to the evaluation of the average number of grazing animals that a specific pasture lands can sustainably support over the course of a season without triggering adverse consequences (Scanlan, et al., 1994; Desta and Coppock, 2002). This quantitative measure is typically denoted as ha/AU/yr. and serves as an indicator of a rangeland's inherent productivity, overall health, and resilience. The estimation of carrying capacity commonly involves a rigorous analysis of long-term forage yield data collected from a particular range site. This information, spanning an extended duration, facilitates a qualitative assessment of the pasture lands and informs judicious decisions regarding stocking rates. Carrying capacity, in essence, establishes the optimal stocking rate for a pasture land during a defined grazing season, expressed in terms of animal unit months (AUM) per unit area (Stoddart et al., 1975).

Carrying capacities were determined by establishing the relationship between forage biomass and the dietary needs of animals based on their live body weight. The daily feed

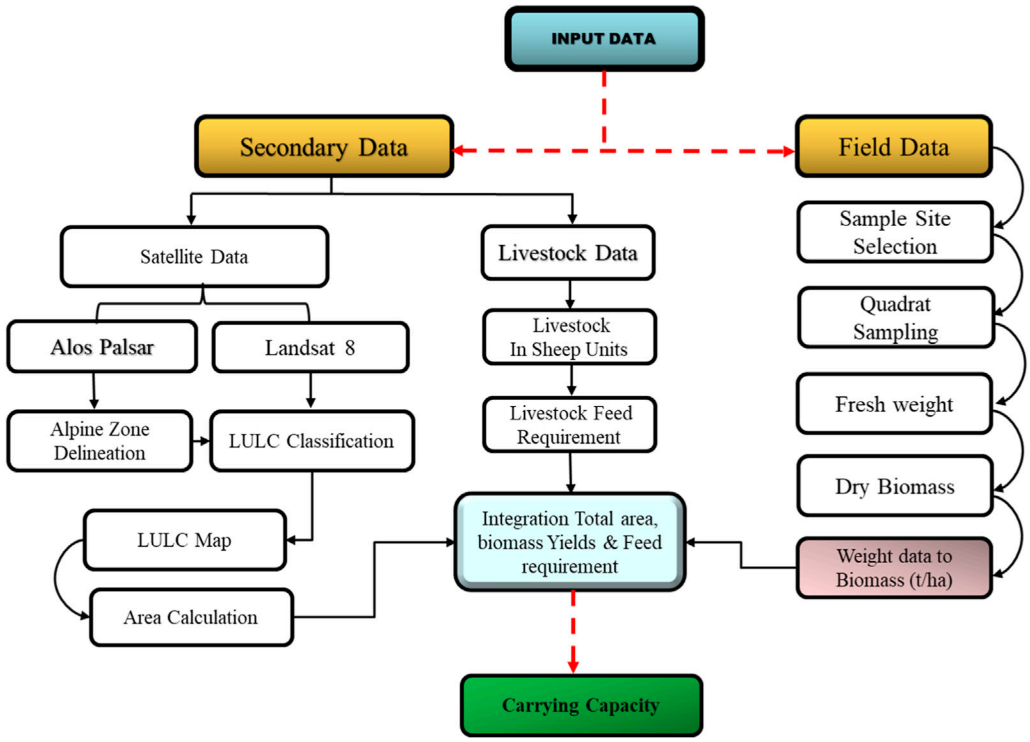

FIGURE 1
Methodology flow chart.

requirements for grazing animals were computed at 2.5% of their live body weight, assuming a 6% crude protein content in the range forage species, as established by Timberlake and Reddy (1986). As a reference, a sheep with an average body weight of 52 kg requiring 1.3 kg of dry matter forage per day (equivalent to 2.5% of its body weight) was considered as one animal unit. Using these parameters, forage consumption within a grazing season amounted to 65 kg per 50 grazing days. Following the methodology outlined by Kent and Coker (1992). In this particular study, the grazing season was defined as 4 months due to the harsh climatic conditions prevalent in the alpine region of Kashmir, limiting grazing availability to this period. However, the carrying capacity was estimated based on a 50-day timeframe, which coincides with the grass regrowth season. The livestock population in the study area predominantly includes local breeds of cattle, cows, buffaloes, horses, sheep, and goats. To accurately assess the carrying capacity of these categories, livestock numbers were standardized into equivalent sheep units. This approach ensures a uniform measure for evaluating the grazing pressure and resource requirements of different livestock types. The following (Equation 1) were used to compute carrying capacity.

$$CC\left(\frac{\frac{\text{ha}}{AU}}{Year}\right) = \frac{\text{Animal Forage Requirement}\left(\frac{\text{kg}}{\text{year or season}}\right)}{\text{Forage Production}\left(\frac{\text{kg}}{\text{ha}}\right)} \tag{1}$$

A proper rangeland carrying capacity is calculated as (using Equation 2).

$$C_c = \frac{F}{I \times D} \tag{2}$$

Wherein CC is maximum number of animals a particular rangeland can support for a specific period without degrading the ecosystem, it's expressed in standard sheep units (SU).

Standard sheep unit (SU): A reference unit used to compare the grazing needs of different livestock types. One SU represents the forage needs of a single adult sheep which is 2.5% live body weight.

Usable forage (F): The amount of forage from the rangeland that's actually available and consumable by grazing animals which is 50%.

Forage intake (I): The daily amount of forage consumed by a standard sheep unit.

Grazing period (D): The total number of days in a year (50 days) that the rangeland is available for grazing.

Stocking rate

The Stocking rate represents the actual number of livestock that can graze a specific area of grassland for a given period

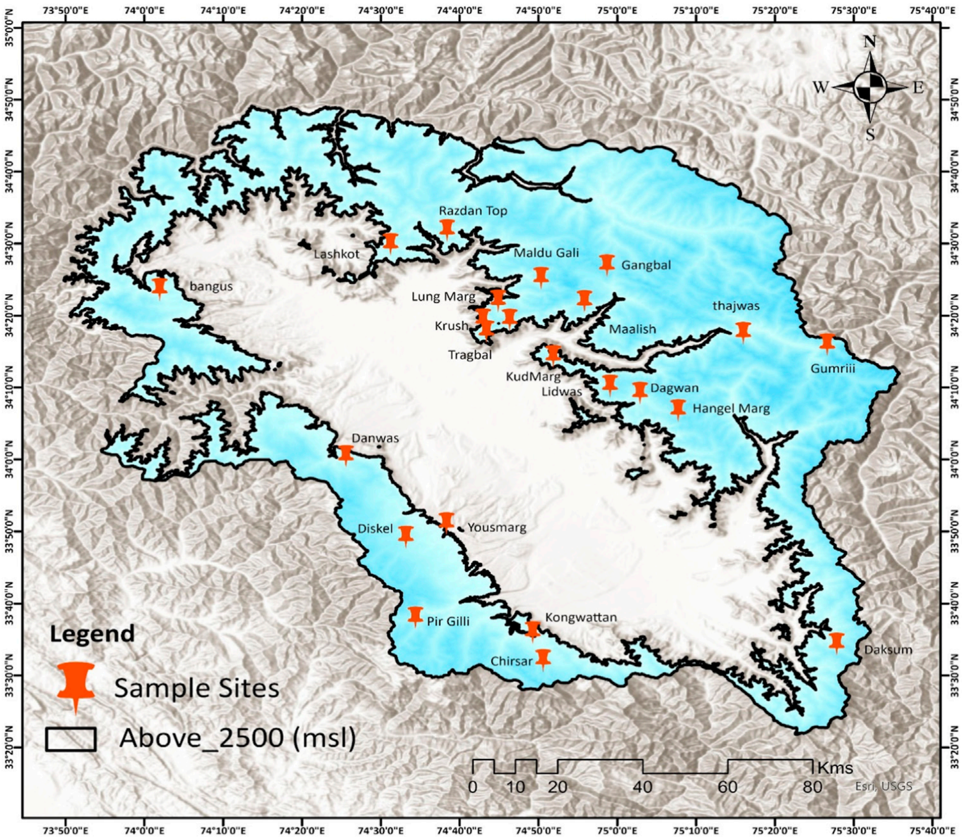

FIGURE 2
Study area map sampled pasture lands.

without harming the ecosystem. It should consider all types of large grazing animals and their meat consumption needs. The formula (Equation 3) for calculating the approximate stocking rate is defined as:

$$S_r = S_c + S_s + S_y + S_m \quad (3)$$

Sr: Real number of livestock (standard sheep unit, SU).

Sc: Number of cattle within a grazing period (converted to standard she ep units).

Ss: Number of goats within grazing period (standard sheep units).

Sy: Number of horses within grazing period (converted to standard sheep units).

Carrying rate

Carrying rate (Cr) emerges as a critical tool for gauging the sustainability of grazing activity. Cr serves as an indicator of whether grazing practices are exceeding the land's capacity. By calculating Cr, ranchers and land managers can determine if their current grazing intensity aligns with the rangeland's ability to support livestock. A negative carrying rate (Cr < 0) signifies a worrisome situation: overgrazing. This scenario occurs when the number of animals grazing the land surpasses its sustainable limit. Conversely, a positive carrying rate (Cr > 0) indicates a more favourable situation with a surplus of available forage. In this case, the grazing pressure is below the rangeland's capacity, suggesting the potential to support more livestock without harm. Finally, a carrying rate of zero (Cr = 0) represents a scenario where grazing activity precisely matches the rangeland's capabilities (using Equation 4).

$$C_r = \frac{C_c - S_r}{C_c} \quad (4)$$

In which, Cr is the carrying rate, Cc is the proper carrying capacity, and Sr is real stocking rate.

Results

The LULC analysis focusing on the alpine and sub-alpine regions of Kashmir was primarily aimed at delineating and quantifying the area under grassland. This was crucial for

TABLE 1 Area under various Land Use types in hectares and percentage.

Class Name	Area in hectares	Percentage (%)
Open Forest	98,147	11.17%
Exposed Rock	345,269	39.28%
Forest	169,367	19.25%
Shrubland	93,117	10.59%
Grassland	160,974	18.32%
Snow	12,159	1.38%
Total	879,033	100.00%

understanding the spatial distribution and extent of grassland ecosystems in the Kashmir Himalayas. Through Maximum likelihood classification method, we have identified six land use classes as given in Table 1. Wherein open forests covered 98,147 ha, which is 11.17% of the total study area. Exposed rock formations were the most extensive, spanning 345,269 ha and accounting for 39.28% of the total land cover. Forested areas measured 169,367 ha, making up 19.25% of the area, while shrublands covered 93,117 ha, representing 10.59% of the landscape and snow-covered regions were relatively limited, covering 12,159 ha or 1.38% of the total area. Grasslands spanned an area of 160,974 ha, constituting 18.32% of the total study area (Figure 3). This land use type was a primary focus of interest due to its crucial role in supporting pastoralism activities during the summer seasons in the region.

Above ground biomass (dry matter)

The investigation of rangelands in the Kashmir Himalayas, covering 23 pasture sites (including portions of sampling pasture land areas that are both grazed and ungrazed), across study area provided valuable insights into their grassland biomass production and growth patterns. The analysis of dry biomass, derived from the collected field data reflecting organic matter after removal of moisture content, reveals variability in grassland productivity as shown in Figure 3. With an average dry matter yield of 5.21 tons per hectare, the total estimated production for the 160,974 ha of grassland in the study region is approximately 838,675 metric tons. The findings show pasture lands like Daksum, Tragbal, Krush, Lung Marg, Lidwas, and Razdan Top, have high dry biomass productivity exceeding 5.99 tons/ha. The pasture lands show moderate levels of biomass

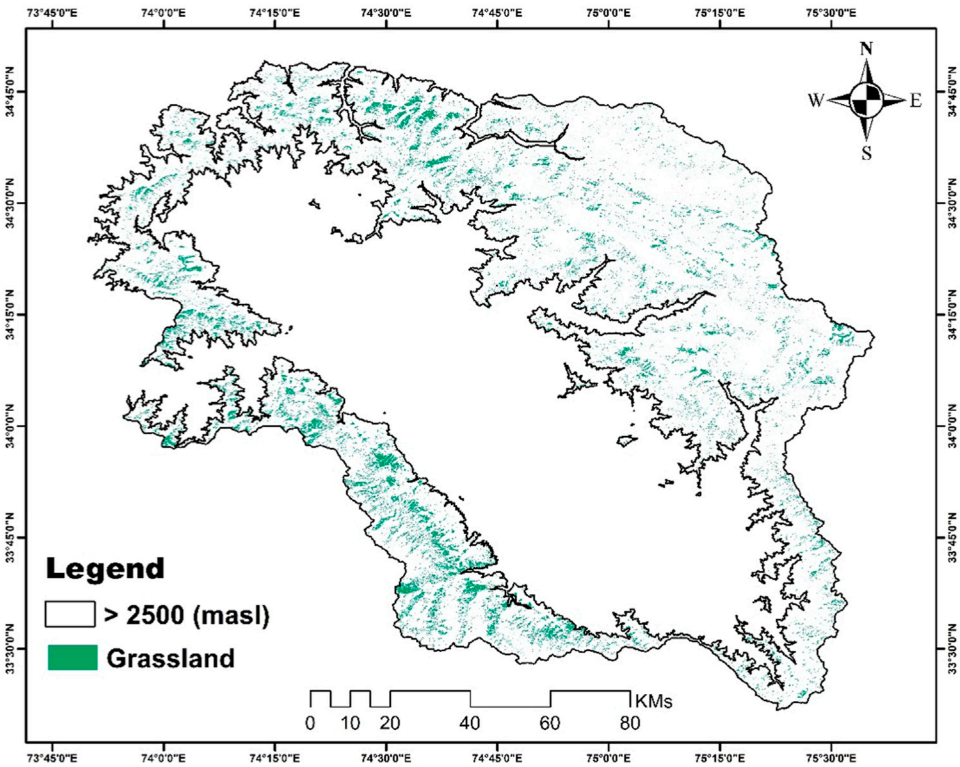

FIGURE 3
Grassland areas identified through land use and land cover assessment.

TABLE 2 Major pastoralists of Jammu and Kashmir.

Name of the community	Composition of livestock	Type of movement
Bakerwal	Mainly goats, sheep, horses and dogs	Nomadic and Transhumance
Gujjars	Cattle, buffaloes, sheep, horses and dogs	Transhumance and sedentary
Chopans	Mainly sheep	Semi-sedentary

TABLE 3 Livestock statistics and forage requirements.

Livestock Name	*Livestock Units*	*Avg Livestock/ Family*	*Weight (KG)*	*Daily Feed Requirement/ AU (Kg)*	*Livestock After conversion into SU (Kg)*	*50 Days Feed Requirement (MT)*
Sheep	12,85,000	16	52 (1SU)	52 × 0.025 = 1.3	65 × 12,85,000	83,525
Goats	851,000	11	52 (1SU)	52 × 0.025 = 1.3	65 × 8,51,000	55,315
Cattle	401,000	5	260(5SU)	260 × 0.025 = 6.5	65 × 20,05,000	130,325
Horses	86,800	1	312(6SU)	312 × 0.025 = 7.8	65 × 520,000	33,800
Total	26,23,800	33			46,61,000	302,965

production are Kongwattan, Gangbal, and Hangel Marg demonstrated yields of 5.84, 5.69, and 5.67 metric tons per hectare, respectively. Dagwan closely followed with 5.44 metric tons, while Lashkoot 5.21, Gumri 5.20, and Bangus 5.16 produced metric tons per hectare. Other sites included Danwas 4.66 t/ha, Pir Galli 4.63 t/ha, Chirsar 4.83 t/ha, Maalish 4.55 t/ha, and Kud Marg 4.29 t/ha, in contrast, Lower-yielding sites such as Thajwas, Mohand Marg, Yousmarg Diskel and Maaldu Gali produced less than 4 metric tons of dry biomass per hectare.

Livestock composition and feed requirement

The livestock population of pastoral migrants in the Kashmir Himalayas is diverse, reflecting varied cultural practices, economic needs, and environmental adaptations. This diversity is evident in the different types of livestock favoured by different pastoral communities, which play a crucial role in their livelihoods and subsistence (See Table 2). Sheep constitute the largest share of the livestock population, with an estimated 12.85 lakh units, accounting for approximately 48.97% of the total livestock. This significant percentage highlights the predominance of sheep in the region's pastoral economy. Goats represent the second-largest group, with a population of 8.51 lakh units, making up about 32.43% of the total livestock. The significant presence of sheep and goat indicates their crucial role in the pastoral system. Their significance lies in their ability to adapt to the region's demanding landscapes and long migration routes, making them essential to the livelihood and economic stability of pastoralist communities. Cattle, numbering (4.01 lac), comprise approximately 15.28% of the total livestock population, also contribute vitally to the pastoral economy. They are important for milk production, ploughing fields, and as a source of meat. The Gujjars, known for maintaining a variety of livestock including cattle, benefit from the diverse products and services cattle provide, which support their semi-nomadic and partially sedentary lifestyle. Horses, with having population of 86.8 thousand, constitute about 3.31% of the total livestock are essential for mobility and transportation, especially for Bakerwals. Understanding this livestock composition is crucial for accurately estimating the carrying capacity of the rangelands. The total forage requirements for livestock (sheep/goats/Cattle/horses) are 302,956 Metric tons have been calculated based on the 2.5% of their body weight for 50 days' time period (Table 3, Figure 4). The daily forage requirements for total sheep units present are 1,670.5 metric tons, and for goats 1,106.3 metric tons, cattle 2,606.5 metric tons, and horses 676 metric tons.

By considering the specific needs and contributions of each livestock type, effective strategies can be developed to optimize the carrying capacity, ensuring the long-term sustainability of pastoralist practices in the Kashmir Himalayas.

Carrying capacity

The Carrying Capacity of the sampled grasslands have been calculated for 50 days timeframe, which corresponds to the renewal period for new grass growth. This timeframe reflects the period required for the grasslands to regenerate sufficient biomass to support grazing animals. By considering this renewal cycle, the carrying capacity assessment ensures sustainable use of the pasture lands without overexploiting the available forage.

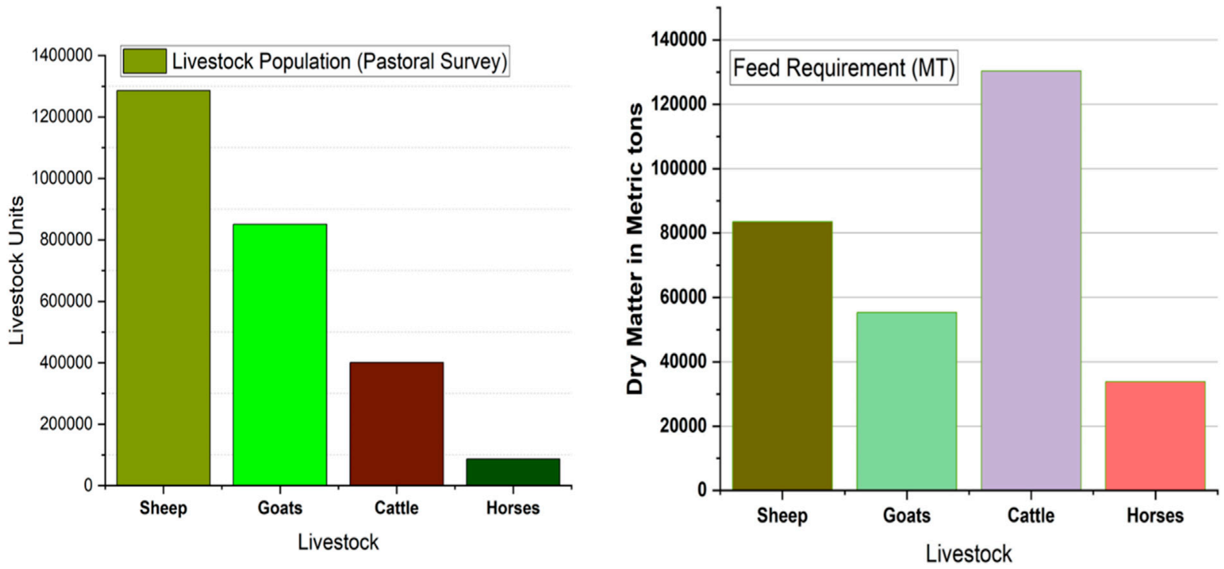

FIGURE 4
Showing livestock composition and their forage requirement.

Carrying capacity have been calculated based on daily fodder requirement of 2.5 percent of body weight of Animal unit (See Table 4). The average carrying capacity observed across the study sites was 39.08 animal sheep units per hectare (Figure 5), with the present stocking rate of 29 Animal Sheep Units/ha, leaving a surplus of 10.06 SU/ha. The total carrying capacity of rangelands spread over an area of 160,974 ha is 62,78,556 whereas the current stocking rate of 4,661,800 SU utilizes about 74.21% of this Carrying capacity, leaving a surplus of 25.77% or 1,616,756 Animal Sheep Units. Pasture land like Daksum (54.54 AU/ha), Tragbal (54.31 AU/ha), Krush (53.54 AU/ha), and Lung Marg (52 AU/ha) recorded the highest carrying capacities. Whereas, pasture lands like Gangbal (43.77 AU/ha), Lidwas (48.54 AU/ha), and Razdan Top (46.08 AU/ha) show a balance of moderate biomass production and sufficient forage supply. Pasture lands like Diskel (29.85 AU/ha) and Maaldu Gali (28.69 AU/ha), Yousmarg (23.46 AU/ha), Mohand Marg (22.08 AU/ha), and Thajwas (18.85 AU/ha), have the lowest carrying capacities, indicating limited forage availability and more fragile ecological conditions.

Discussion

The findings of the present study offer a valuable insight into the forage dynamics and livestock carrying capacity of the alpine grasslands in the Kashmir Himalayas, which are crucial for supporting pastoral livelihoods and maintaining the ecological balance of these fragile ecosystems. The results highlight the substantial biomass production of these grasslands and emphasize their potential to support a higher stocking rate than is currently utilized. To fully harness this potential, it is essential to implement a strategic plan that actively involves a diverse range of stakeholders, including pastoralists and policymakers. On the other hand, concerns over the unequal distribution of grazing pressure and the long-term viability of these rangelands due to localized overgrazing in places where tourism overlap. The results indicate lower biomass production in some low-elevated pasture lands, that are generally anticipated to exhibit high productivity, the finding suggests an inverse trend attributable to intensive overgrazing practices due to their transformation into tourist destinations. Key factors contributing to this reduced biomass include the overstocking of horses, combined with grazing by livestock from pastoral communities. Consequently, this overgrazing has led to a significant decrease in both the carrying capacity and overall productivity of these pasture lands (Husain et al., 2021; Ashraf et al., 2012). The outcomes prompt for a more in-depth analysis of sustainable pastoralism, emphasizing the importance of adaptive management practices to maintain the productivity and ecological integrity of grasslands.

The findings of this study align with the results reported by (Dad, 2019), indicating a similar pattern of AGB distribution in the region. Additionally, the results indicate lower biomass production in some low-elevation pasture lands, such as Thajwas and Yousmarg, which have become semi-degraded due to their development as tourist destinations. Key factors contributing to this reduced biomass include the overstocking of horses, combined with grazing by livestock from pastoral communities.

In temperate continental grasslands, forage availability during harsh winter periods is a critical factor limiting livestock populations (Hui and Jackson, 2006; Rao et al., 2015; Nandintsetseg et al., 2018; Piipponen et al., 2022). The results of

TABLE 4 Carrying capacity and dry matter production across sampled grasslands.

Pasture lands	Dry Biomass (MT/ha)	Carrying Capacity (SU/ha)
Mohand Marg	2.87	22.08
Tragbal	7.06	54.31
Krush	6.96	53.54
Lung Marg	6.76	52.00
Maaldu Gali	3.73	28.69
Kud Marg	4.29	33.00
Gangbal	5.69	43.77
Dagwan	5.44	41.85
Maalish	4.55	35.00
Thajwas	2.45	18.85
Razdan Top	5.99	46.08
Gumri	5.20	40.00
Daksum	7.09	54.54
Lidwas	6.31	48.54
Hangel Marg	5.67	43.62
Diskel	3.88	29.85
Pir Galli	4.63	35.62
Bangus	5.16	39.69
Lashkoot	5.21	40.08
Danwas	4.66	35.85
Chirsar	4.83	37.15
Yousmarg	3.05	23.46
Kongwattan	5.84	44.92

our study share several key similarities with other global rangeland ecosystems, particularly regarding forage dynamics, the grassland yield in the Kashmir Himalayas 5.10 metric tons per hectare is significantly higher than the estimated average yield for the Three-River Headwaters region in China, where studies report values around 442.5 kg/ha (Fan et al., 2011). This difference in yield can be attributed to varying environmental conditions, such as altitude, precipitation, and temperature, as well as the methods of calculation. The study in the Three-River Headwaters utilized NOAA/AVHRR data, while ours is based on biomass sampling and local field measurements, providing a more direct and region-specific estimation.

Although the current stocking level is 29 sheep units (SU) and the carrying capacity is 39 SU, the availability of forage in winters continues to limit optimal livestock numbers, alongside other factors. Various elements such as ecological zones, seasonality, water availability, elevation, and livestock trampling can significantly influence forage availability in grassland ecosystems. While determining precise forage utilization is challenging, a 50% utilization rate is generally recommended to maintain rangeland health (Holechek, 1988; Liang et al., 2002; Wang et al., 2011; Su et al., 2017). Despite an overall surplus in carrying capacity, localized overgrazing near huts, water sources, and in intervening pasture lands remains a significant challenge, as reported by Lamba (2015) in Spiti, that areas around water sources, assessed using shorter transects, face intense species degradation. Overgrazing is known to negatively impact rangeland quality (Fleischner, 1994). This localized pressure has led to a decline in biomass production and a reduction in carrying capacity in these areas. As nomadic lifestyles become more sedentary, grazing-induced degradation in certain areas may intensify due to more frequent and concentrated grazing pressure (Vetter, 2005).

Rangelands with lower carrying capacities require careful management to avoid overgrazing, while those with moderate productivity support balanced livestock numbers with appropriate oversight. High-productivity regions can sustain

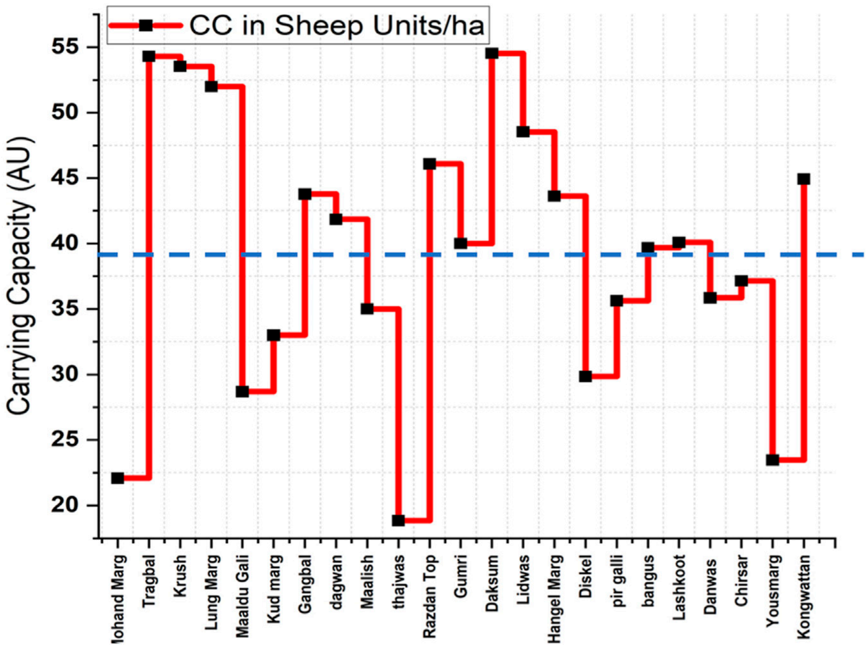

FIGURE 5
Livestock carrying capacity across sampled grasslands.

larger livestock populations, though the buffer capacity has diminished, particularly where tourism and grazing overlap, leading to overgrazing in some areas. The findings underscore the need for strategic management to balance livestock demand with sustainable rangeland use, ensuring long-term productivity in the region.

To ensure the sustainability of these grasslands, it is recommended that localized management strategies to address areas experiencing overgrazing by implementing rotational grazing systems, where livestock are moved between different grazing areas based on forage availability and recovery periods. This approach, already a key aspect of local pastoral management, has successfully maintained a balance in rangeland biodiversity. The study shows that pasturelands like Daksum, Tragbal, Krush, Lung Marg, Lidwas, and Razdan used seasonally by Gujjer Bakerwal and Chopans pastoral communities, maintain high productivity reflects positive outcomes from these practices. Additionally, strengthening community-based rangeland management approaches, where local pastoralists play an active role in monitoring and managing grazing practices, is essential for effective resource use. Policymakers should also consider establishing forage reserves or creating alternative grazing areas to reduce pressure on sensitive ecosystems, particularly during periods of drought or forage scarcity.

Further, integrating traditional knowledge with scientific approaches, such as GIS-based monitoring, could enhance pasture management by providing real-time data on forage conditions and livestock movements. Engaging pastoralists in educational programs that promote sustainable grazing practices and awareness of stocking limits would also foster greater stewardship of the grasslands.

Future research may focus on more detailed and localized assessments of forage availability, quality, and seasonal dynamics. Conducting longer-term monitoring of forage productivity, coupled with data on climate variability, would provide a clearer understanding of how these grasslands are responding to changing environmental conditions. Additionally, research on soil health, including studies on root biomass, nutrient cycling, and the impacts of grazing on soil compaction and erosion, is crucial for developing a more comprehensive picture of rangeland sustainability.

Investigating the socio-economic factors influencing pastoralist behaviour, such as decision-making processes related to livestock numbers, migration patterns, and grazing practices, would also be valuable for designing effective management interventions. Lastly, exploring the potential of integrating climate-resilient forage species or improved livestock breeds could offer innovative solutions for enhancing the productivity and resilience of these rangelands in the face of climate change.

Conclusion

The study identifies critical zones where localized overgrazing poses a threat to the ecological health of the rangelands. The findings suggest that, despite grazing pressures, the broader alpine grasslands of the Kashmir

Himalayas remain resilient and productive, largely due to the sustainable practices employed by pastoral communities. However, the increasing influence of tourism in these sensitive regions, underscores the need for balanced policies. Proper management strategies must ensure that tourism and grazing pressures are harmonized to prevent further degradation of these fragile ecosystems. The study advocates for a balanced approach that optimizes land use while preserving the ecological integrity of the rangelands. The findings provide a valuable framework for policymakers and pastoralists alike to ensure the long-term sustainability of the Kashmir Himalayas' alpine grasslands. However, future research should focus on long-term monitoring, climate change impacts, soil health, economic analysis, sustainable grazing practices, and community engagement to ensure sustainable management and conservation of these vital grasslands.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

All the ethical standards of research publishing were taken care of during this study.

Author contributions

SS and JR originated the idea and planned to carry out the research work. SS, SA, RA, and JR downloaded and processed data as well as devised the methodology. SS and SA conducted the field sampling. JR and SS interpreted the results. SS took charge of writing the manuscript, while JR, SA, and LH edited and revised it. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Akiyama, T., and Kawamura, K. (2007). Grassland degradation in China: methods of monitoring, management and restoration. *Grassl. Sci.* 53 (1), 1–17. doi:10.1111/j.1744-697x.2007.00073.x

Ashraf, M., Bhat, G. A., Dar, I. Y., and Ali, M. (2012). Physico-chemical characteristics of the grassland soils of yusmarg hill resort (Kashmir, India). *Ecol. Balk.* 4 (1).

Biró, M., Molnár, Z., Babai, D., Dénes, A., Fehér, A., Barta, S., et al. (2019). Reviewing historical traditional knowledge for innovative conservation management: a re-evaluation of wetland grazing. *Sci. Total Environ.* 666, 1114–1125. doi:10.1016/j.scitotenv.2019.02.292

Bogaerts, M., Cirhigiri, L., Robinson, I., Rodkin, M., Hajjar, R., Costa Junior, C., et al. (2017). Climate change mitigation through intensified pasture management: Estimating greenhouse gas emissions on cattle farms in the Brazilian amazon. *J. Clean. Prod.* 162, 1539–1550. doi:10.1016/j.jclepro.2017.06.130

Briske, D. D., Derner, J. D., Brown, J. R., Fuhlendorf, S. D., Teague, W. R., Havstad, K. M., et al. (2015a). Strategies for global rangeland management. *Rangel. Ecol. and Manag.* 68 (5), 467–479. doi:10.1111/1365-2664.13610

Briske, D. D., Zhao, M., Han, G., Xiu, C., Kemp, D. R., Willms, W., et al. (2015b). Strategies to alleviate poverty and grassland degradation in Inner Mongolia: intensification vs production efficiency of livestock systems. *J. Environ. Manag.* 152, 177–182. doi:10.1016/j.jenvman.2014.07.036

Cao, Y. N., Wu, J. S., Zhang, X. Z., Niu, B., Li, M., Zhang, Y., et al. (2019). Dynamic forage-livestock balance analysis in alpine grasslands on the Northern Tibetan Plateau. *J. Environ. Manag.* 238, 352–359. doi:10.1016/j.jenvman.2019.03.010

Chander, G., and Markham, B. (2003). Revised landsat-5 tm radiometric calibration procedures and postcalibration dynamic ranges. *IEEE Trans. Geoscience Remote Sens.* 41 (11 PART II), 2674–2677. doi:10.1109/TGRS.2003.818464

Dad, J. M. (2019). Organic carbon stocks in mountain grassland soils of northwestern Kashmir Himalaya: spatial distribution and effects of altitude, plant diversity and land use. *Carbon Manag.* 10 (2), 149–162. doi:10.1080/17583004.2019.1568137

Dad, J. M., and Khan, A. B. (2010). Floristic composition of an alpine grassland in Bandipora, Kashmir. *Grassl. Sci.* 56 (2), 87–94. doi:10.1111/j.1744-697x.2010.00179.x

Desta, S., and Coppock, L. (2002). Cattle population dynamics in the southern Ethiopian rangelands, 1980–97. *J. Range Manag.* 55 (5), 439–451. doi:10.2307/4003221

Dong, S., Shang, Z., Gao, J., and Boone, R. (2022). Enhancing the ecological services of the Qinghai-Tibetan Plateau's grasslands through sustainable restoration and management in era of global change. *Agric. Ecosyst. and Environ.* 326, 107756. doi:10.1016/j.agee.2021.107756

Fan, J. W., Shao, Q. Q., Wang, J. B., Chen, Z., and Zhong, H. (2011). An analysis of temporal spatial dynamics of grazing pressure on grassland in Three Rivers Headwater Region. *Chin. J. Grassl.* 33 (3), 64–72.

FAO (2018). Faostat. *Food Agric. Organ. U. N.*

FAO (2019). Faostat. *Food Agric. Organ. U. N.*

Fassnacht, F. E., Li, L., and Fritz, A. (2015). Mapping degraded grassland on the Eastern Tibetan Plateau with multi-temporal Landsat 8 data—where do the severely degraded areas occur? *Int. J. Appl. Earth Observation Geoinformation* 42, 115–127. doi:10.1016/j.jag.2015.06.005

Fleischner, T. L. (1994). Ecological costs of livestock grazing in western North America. *Conserv. Biol.* 8, 629–644. doi:10.1046/j.1523-1739.1994.08030629.x

Fuhlendorf, S. D., and Engle, D. M. (2001). Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. *BioScience* 51 (8), 625–632. doi:10.1641/0006-3568(2001)051[0625:rhorem]2.0.co;2

Golluscio, R. A., Bottaro, H. S., and Oesterheld, M. (2015). Controls of carrying capacity: degradation, primary production, and forage quality effects in a Patagonian steppe. *Rangel. Ecol. and Manag.* 68 (3), 266–275. doi:10.1016/j.rama.2015.03.002

Holechek, J. L. (1988). An approach for setting the stocking rate. *a Society* 10 (1), 1.

Hua, L., and Squires, V. R. (2015). Managing China's pastoral lands: current problems and future prospects. *Land Use Policy* 43, 129–137. doi:10.1016/j.landusepol.2014.11.004

Hui, D., and Jackson, R. B. (2006). Geographical and interannual variability in biomass partitioning in grassland ecosystems: a synthesis of field data. *New Phytol.* 169 (1), 85–93. doi:10.1111/j.1469-8137.2005.01569.x

Hunt, E. R., Everitt, J. H., Ritchie, J. C., Moran, M. S., Booth, D. T., Anderson, G. L., et al. (2003). Applications and research using remote sensing for rangeland management. *Photogramm. Eng. Rem. S.* 69 (6), 675–693.

Hunt, E. R., and Miyake, B. A. (2006). Comparison of stocking rates from remote sensing and geospatial data. *Rangel. Ecol. and Manag.* 59 (1), 11–18. doi:10.2458/azu_jrm_v59i1_hunt

Husain, M., Geelani, S. N., and Bhat, G. M. (2021). Effect of grazing on carbon stock and biomass production in temperate grassland of Kashmir, India. *Range Manag. Agrofor.* 42 (1), 1–6.

Kent, M., and Coker, P. (1992). "Vegetation description and analysis: a practical approach," in *This book offers comprehensive methods for vegetation analysis and is useful for calculating forage consumption over a grazing season or year based on animal units* (John Wiley and Sons).

Körner, C., Nakhutsrishvili, G., and Spehn, E. (2006). "High-elevation land use, biodiversity, and ecosystem functioning," in *Land use change and mountain biodiversity* (Boca Raton, FL: CRC Press), 3–36.

Lamba, A. (2015). *Assessing the impacts of livestock grazing in the trans-himalayan rangelands of Spiti, India*. Doctoral Dissertation. Silwood Park Campus, United Kingdom: Department of Life Sciences, Silwood Park, Imperial College London.

Li, M., He, Y. T., Fu, G., Shi, P. L., Zhang, X. Z., Sun, J., et al. (2016). Livestock-forage balance in the Three River Headwater Region based on the terrestrial ecosystem model. *Ecol. Environ. Sci.* 25 (12), 1915–1921. (in Chinese).

Liang, C., Guo, Y., Wang, J., and Li, X. (2002). Rangeland health and the impact of grazing in grasslands. *J. Grassl. Sci.* 25 (4), 245–253.

Liu, Y., Wang, Q., Zhang, Z., Tong, L., Wang, Z., and Li, J. (2019). Grassland dynamics in responses to climate variation and human activities in China from 2000 to 2013. *Sci. total Environ.* 690, 27–39. doi:10.1016/j.scitotenv.2019.06.503

Meng, H., Yang, J., Sun, W., Xiao, L., and Wang, G. (2022). Aboveground biomass in China's managed grasslands and their responses to environmental and management variations. *Agronomy* 12 (12), 2913. doi:10.3390/agronomy12122913

Milchunas, D. G., and Lauenroth, W. K. (1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecol. Monogr.* 63 (4), 327–366. doi:10.2307/2937150

Mushtaq, S., Saleem, S., Ahmed, R., Tass, M. S., Rather, J. A., and Rather, G. M. (2024). Spatio-temporal analysis land use land cover changes in South Kashmir region of North-western Himalayas using Landsat data. *Discov. Geosci.* 2 (1), 37. doi:10.1007/s44288-024-00031-3

Nandintsetseg, B., Boldgiv, B., and Ojima, D. (2018). The impact of climate change on grassland degradation. *J. Arid Environ.* 157, 89–98.

Oesterheld, M., Sala, O. E., McNaughton, S. J., and Levine, J. M. (1992). Effect of animal husbandry on herbivore carrying capacity at a regional scale. *Nature* 356 (6369), 234–236. doi:10.1038/356234a0

Palermo, G. C., d'Avignon, A. L. d. A., Freitas, M. A. V., and Freitas, M. A. V. (2014). Reduction of emissions from Brazilian cattle raising and the generation of energy: Intensification and confinement potentials. *Energy Policy* 68, 28–38. doi:10.1016/j.enpol.2014.01.041

Piao, S. L., Fang, J. Y., He, J. S., and Xiao, Y. (2004). Spatial distribution of grassland biomass in China. *Acta Phytoecol. Sin.* 28 (4), 491–498. (in Chinese).

Piipponen, J., Mikkola, K., and Tømmervik, H. (2022). Winter forage availability in high-latitude rangelands: a limiting factor for livestock populations. *Rangel. Ecol. and Manag.* 75, 1032–1044.

Rao, S., Nandintsetseg, B., Boldgiv, B., and Ojima, D. S. (2015). Climate variability and pastoralism in the Mongolian Plateau. *Pastor. Res. Policy, Pract.* 5 (1), 16.

Rawat, G. S. (1998). Temperate and alpine grasslands of the himalaya: Ecology and conservation. *Parks* 8 (3), 27–36.

Rawat, G. S. (2005). Terrestrial vegetation and ecosystem coverage within Indian protected areas. *Natl. Acad. Sci. Lett.* 28 (7/8), 241.

Roy, A. K., and Singh, J. P. (2013). Grasslands in India: problems and perspectives for sustaining livestock and rural livelihoods. *Trop. Grassl. Trop.* 1 (2), 240–243. doi:10.17138/tgft(1)240-243

Saleem, I., Mugloo, J. A., Anjum Baba, A., and Buch, K. (2019). Biomass estimation of herbaceous species of Benhama area, Kashmir. *J. Pharmacogn. Phytochem.* 8, 2926–2929.

Saleem, S., Ahmed Hajam, F., and Rather, J. A. (2021). Spatio-temporal analysis of land use land cover changes in sind catchment of the Kashmir Valley, India. Geo. *Eye* 10 (2), 35–42. doi:10.53989/bu.ge.v10i2.7a

Saleem, S., Rather, J. A., Ahmed, S., Mushtaq, S., Ahmed, R., and Malik, I. H. (2024). Above ground biomass estimation for alpine grasslands of Kashmir Himalayas using remote sensing and field-data. *Rangel. Ecol. and Manag.* 96, 117–127. doi:10.1016/j.rama.2024.06.001

Scanlan, J. C., McKeon, G. M., Day, K. A., Mott, J., and Hinton, A. (1994). Estimating safe carrying capacities of extensive cattle-grazing properties within tropical, semi-arid woodlands of north-eastern Australia. *Rangel. J.* 16 (1), 64–76. doi:10.1071/rj9940064

Scurlock, J. M. O., and Hall, D. O. (1998). The global carbon sink: a grassland perspective. *Glob. Change Biol.* 4 (2), 229–233. doi:10.1046/j.1365-2486.1998.00151.x

Sharifian, A., Fernández-Llamazares, Á., Wario, H. T., Molnár, Z., and Cabeza, M. (2022). Dynamics of pastoral traditional ecological knowledge: A global state-of-the-art review. *Ecol. Soc.* 27 (1), art14. doi:10.5751/es-12918-270114

Singh, J. P., Ahmad, S., Radotra, S., Dev, I., Mir, N. H., Deb, D., et al. (2018). Extent, mapping and utilization of grassland resources of Jammu and Kashmir in western himalaya: A case study. *Range Management and Agroforestry* 39(2), 138–146.

Stoddart, L. A., Smith, A. D., and Box, T. W. (1975). "Range management," in *This classic text provides guidelines on sustainable grazing practices, including the recommendation to exclude 50% of available forage as a safe use factor when determining carrying capacity.* 3rd ed. New York: McGraw-Hill.

Su, Y. Z., Li, Y. L., Cui, H. Y., and Zhao, W. Z. (2017). Utilization rates of grassland ecosystems in northern China. *J. Arid Land* 9 (2), 235–245.

Teague, R., Provenza, F., Kreuter, U., Steffens, T., and Barnes, M. (2013). Multi-paddock grazing on rangelands: Why the perceptual dichotomy between research results and rancher experience. *J. Environ. Manag.* 128, 699–717. doi:10.1016/j.jenvman.2013.05.064

Thornton, P. K., and Herrero, M. (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proc. Natl. Acad. Sci. U. S. A.* 107, 19667–19672. doi:10.1073/pnas.0912890107

Timberlake, J. R., and Reddy, V. (1986). "Use of the digestible dry matter intake method to determine carrying capacity in range lands," in *This reference discusses how to calculate the daily feed requirements based on the live body weight of grazing animals, considering the quality of the range forage*.

Tong, C., Wu, J., Yong, S.-P., Yang, J., and Yong, W. (2004). A landscape-scale assessment of steppe degradation in the Xilin River Basin, Inner Mongolia, China. *J. Arid Environ.* 59, 133–149. doi:10.1016/j.jaridenv.2004.01.004

Vetter, S. (2005). Rangelands at equilibrium and non-equilibrium: Recent developments in the debate. *J. Arid Environ.* 62 (2), 321–341. doi:10.1016/j.jaridenv.2004.11.015

Wang, S. P., Zhou, G. S., and Han, X. G. (2011). Grassland degradation in northern China. *Environ. Sci. Policy* 5 (2), 75–81.

Xu, B., Yang, X., Tao, W., Miao, J., Yang, Z., Liu, H., et al. (2013). MODIS-based remote-sensing monitoring of the spatiotemporal patterns of China's grassland vegetation growth. *Int. J. Remote Sens.* 34, 3867–3878. doi:10.1080/01431161.2012.762696

Yu, M., Ellis, J. E., and Epstein, H. E. (2004). Regional analysis of climate, primary production, and livestock density in Inner Mongolia. *J. Environ. Qual.* 33, 1675–1681. doi:10.2134/jeq2004.1675

Zargar, M. A., and Shah, S. A. (2012). Kashmir saffron (crocus sativus L.): a review on its cultivation, processing, and uses. *J. Med. Plants Res.* 6 (2), 274–282.

Zhou, H., Zhao, X., Tang, Y., Gu, S., and Zhou, L. (2005). Alpine grassland degradation and its control in the source region of the Yangtze and Yellow Rivers, China. *Grassl. Sci.* 51 (3), 191–203. doi:10.1111/j.1744-697x.2005.00028.x

Zhou, H. K., Zhou, L., Zhao, X. Q., Liu, W., Yan, Z. L., and Shi, Y. (2003). Degradation process and integrated treatment of "black soil beach" type degraded grassland in the source regions of Yangtze and Yellow Rivers. *Chin. J. Ecol. in Chin.* 22 (5), 51–55.