Integrating GIS and MCDA for Pasture Land Suitability Evaluation in Ak-Talaa District of Kyrgyzstan

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Abstract

This study used a combination of GIS and Multi-Criteria Decision Analysis (MCDA) to evaluate pasture suitability in the Ak-Talaa district of Kyrgyzstan. The main goal was to identify high-value grazing areas. It also analyzed the natural and anthropogenic factors contributing to their degradation. Consequently, 52,581.69 ha of spring-autumn and winter pastures and 134,063.8 ha of summer pastures were selected as priority grazing zones, which included highly, moderately, and marginally suitable pastures. These zones are especially concentrated in areas where extensive livestock husbandry and other activities are putting more strain on the area.

One of the key challenges revealed was the underuse of remote pasture land, largely caused by a lack of infrastructure and existing land degradation. In practice, the outcomes may assist relevant ministries organize and assign priority improvement of infrastructure, as well as assist experts and local authorities plan seasonal pastures, allocate livestock as efficiently as possible, and take caring capacity into consideration when making management decisions. All of these applications support more evidence-based and sustainable pasture resource management.

Keywords:

GIS, multi-criteria decision analysis, pastureland, ahp, suitability evaluation

1 Introduction

Livestock farming plays a key role in ensuring the region's food security, exerting a multifaceted economic and social impact. It determines the structure of feed demand, the level of competition in the agricultural market, influences agricultural production intensification, farm profitability, and land use patterns, and is directly linked to the quality of nutrition and public health. Over the past ten years, there has been a steady increase in livestock numbers in small-scale agribusinesses, such as peasant farms and individual entrepreneurs, with particularly noticeable growth in private farms.

Pasture resource management has become a critical national issue in the Kyrgyz Republic due to several interrelated environmental, economic, and institutional factors.

Over recent decades, livestock numbers have shown consistent growth, with herd inventories expanding at a much faster rate than sales or self-consumption (Yang et al., 2022). Official statistics indicate that the livestock population rose over the 14-year period from 2010 to 2024, rising from approximately 1.3 million to 1.83 million head (National Statistical Committee of the Kyrgyz Republic [NSC], 2024). This trend reflects the intensification of livestock production in Kyrgyzstan, driven by population growth and increasing demand for livestock products.

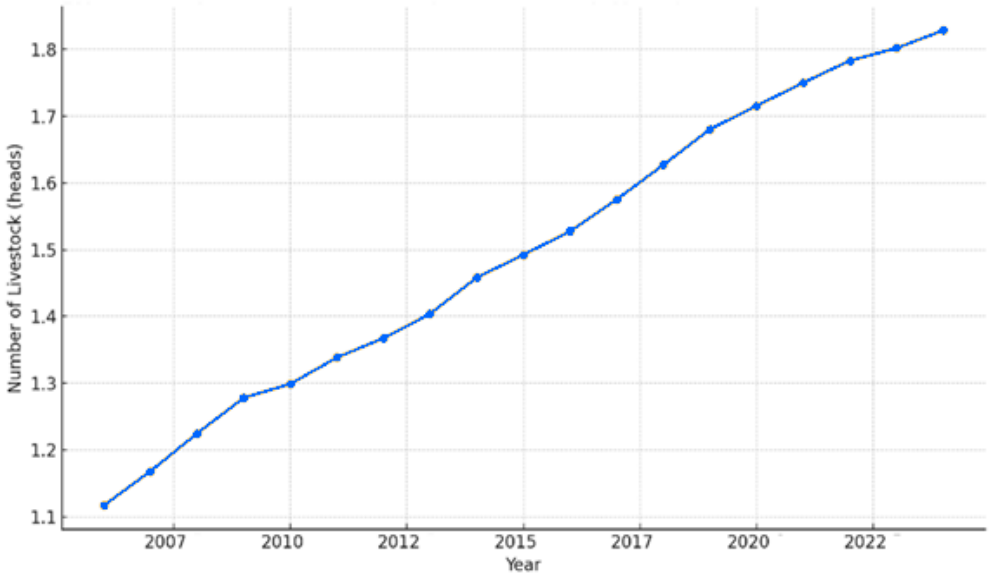


Figure 1: Livestock dynamics in Kyrgyzstan from 2007 to 2024 (NSC, 2024)

However, this growth, combined with unsustainable grazing practices, has contributed to the widespread degradation of pastureland across the country.

Between 2006 and 2024, the share of pasture lands in Kyrgyzstan decreased from 9189.1 thousand hectares to 8985.8 thousand hectares, demonstrating a stable negative trend (NSC, 2024).

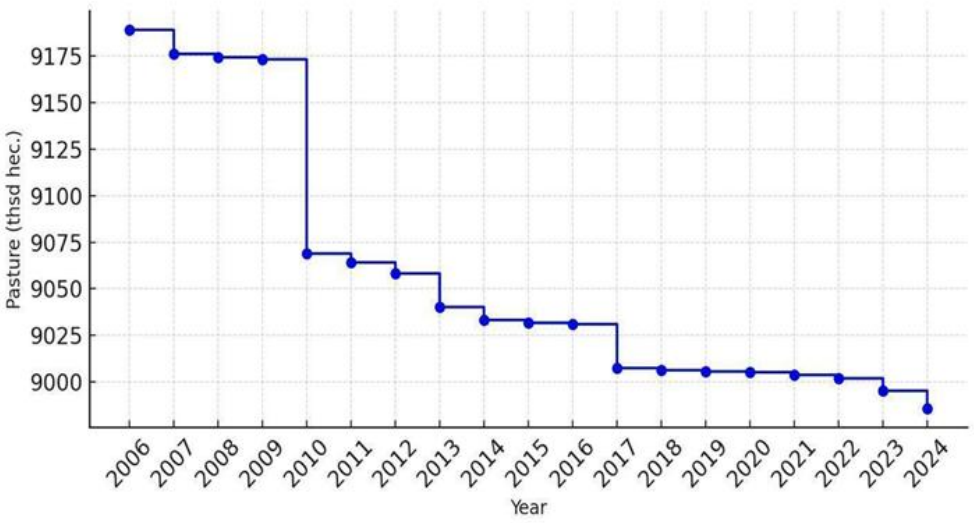


Figure 2: Area of the pasture land from 2006 to 2024 (NSC, 2024)

Other negative factors influence the reduction and degradation of pasture area. Firstly, some pasture land has been transformed for other categories - construction, crop farming, infrastructures and others (Shigaeva et al., 2007; Dörre & Borchardt, 2012). Secondly, climate change is negatively affecting grass growth and the overall health of ecosystems (Tomaszewska & Henebry, 2021). Thirdly, soil erosion, and weak pasture governance also have negative impacts (Sartbaeva, 2021; Duulatov et al., 2021). All of these factors lead to a reduction in the area and a decline in their quality, which threatens the sustainability of livestock farming and the ecological balance in the country. Despite the importance of this issue, there is a lack of comprehensive spatially explicit studies on pasture suitability assessment in Kyrgyzstan. To the best of our knowledge, no previous research has systematically applied GIS-based MCDA for detailed pasture suitability mapping at the district level in the country.

Pasture degradation is especially pronounced in areas near villages and along roads, where excessive grazing has resulted in the loss of productive vegetation and the proliferation of weeds and poisonous plant species (Kilyazova et al., 2019). In contrast, remote mountain pastures remain underutilized, largely due to insufficient infrastructures such as roads, bridges, watering facilities, and electricity. This uneven distribution of grazing pressure is closely linked to the disruption of traditional transhumance systems. The decline of these seasonal migration practices has intensified pressure on foothill pastures - typically located in densely populated areas - while distant highland pastures remain unused and degraded due to poor accessibility (Hoppe et al., 2016). Consequently, the breakdown of transhumance cycles has not only diminished the ecological productivity of pasture land but also undermined the socioeconomic stability of rural communities that rely on grazing and livestock rearing as their primary livelihoods. The erosion of traditional herding practices further threatens the cultural heritage and social cohesion of pastoral communities.

Effective pasture management depends on the accurate assessment of land suitability for grazing, taking into account both the current condition of pastures and their potential for sustainable use (Tomaszewska & Henebry, 2021). Land managers can compare pasture quality, determine the best grazing zones, and support evidence-based decisions for sustainable land management, effective resource allocation, and long-term ecosystem resilience by using spatially explicit evaluation techniques. In this regard, strong tools for mapping environmental elements like topography, vegetation cover, water supply, and natural hazards are provided by GIS and RS. In order to determine pasture suitability and prioritize management measures, MCDA, in particular the AHP, has demonstrated efficacy in integrating quantitative data and expert knowledge.

Recent administrative-territorial reforms have reduced the number of Aiyl Aimaks (rural municipalities) from 452 to 235 (Government of the Kyrgyz Republic [GKR], 2023) and decentralized pasture management responsibilities to municipal enterprises, further emphasizing the need for evidence-based, spatially explicit tools. Integrating GIS and MCDA with governance considerations enables local authorities and specialists to plan seasonal grazing, optimize livestock distribution, and address management challenges, thereby promoting the long-term productivity and ecological sustainability of pasture resources.

The importance for spatially explicit evaluation methods that can assist local authorities in making evidence-based decisions is highlighted by these developments as well as the continued degradation of pastures. By integrating GIS and MCDA with governance considerations, experts may schedule seasonal grazing, allocate resources optimally, and effectively manage issues, all of which support pasture resources' long-term productivity and ecological sustainability.

By integrating environmental, social, and infrastructure factors, the study aims to create a spatially explicit approach to assess pasture suitability in Ak-Talaa district. It provides reliable and sustainable pasture management by identifying high-value pastures using MCDA and AHP-GIS methodologies.

2 Materials and Methods

2.1 Study Area

Ak-Talaa is situated in western part of Naryn region, which is located in the north part of Kyrgyzstan. This district represents a complex mountainous landscape characterized by high elevation, steep slopes, and diverse climatic and ecological conditions. These factors make the region an ideal case study for testing spatial decision-making methods in pasture management. The region is characterized by a predominantly mountainous landscape, with highland zones covering 60 percent of the territory and valleys making up the remaining 40 percent. The territory is located at an altitude of 1600-5100 m above sea level.

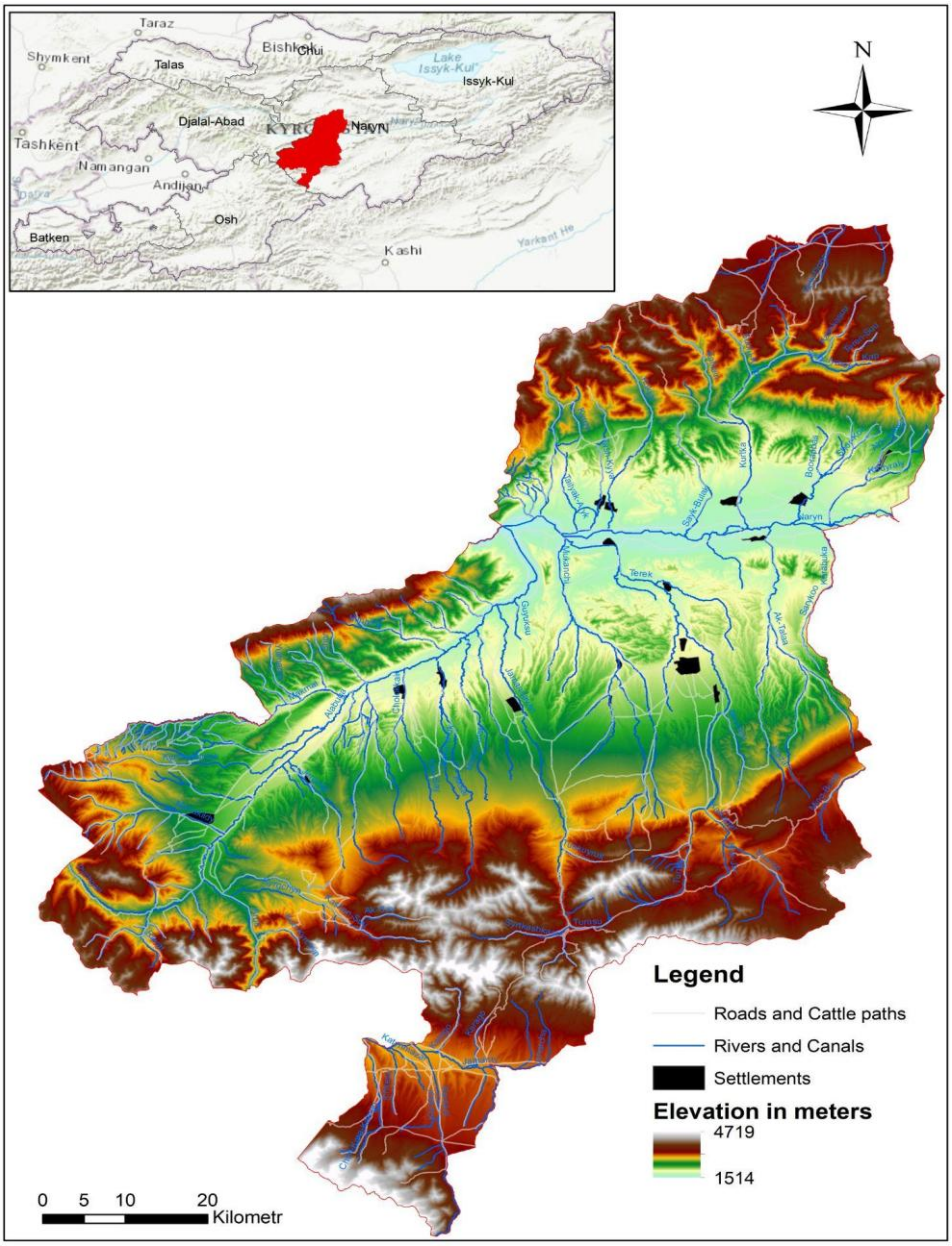


Figure 3: Spatial extent of the study area: Ak-Talaa District, Kyrgyzstan

The climate of the area is dry and sharply continental. However, due to pronounced vertical zonation, there is an extraordinary diversity of microclimatic conditions depending on the altitude, aspect, and slope curvature. The average annual precipitation is 200-500 mm, the average maximum temperature in July reaching approximately 25°C - 27°C and average minimum temperatures in January range from 20 °C - 22°C (World Food Programme, 2024).

Temperature and precipitation change directly impacts biomass productivity, vegetation composition, soil moisture availability, and the length of the grazing season across different altitudinal zones, these climatic gradients are essential for evaluating pasture suitability.

Before the administrative-territorial reform in 2023, there were 13 Aiyl aimaks (AA) in the Ak-Talaa district. After the reform, numbers were reduced to four: Ala-Buga, Baetov, Kara-Burgon, and Togolok-Moldo (GKR, 2023). These consolidated aimaks now include 19 villages.

2.2 Methodology

The study used a GIS and MCDA framework to identify high-value pastures and the Ak-Talaa district, Kyrgyzstan. This approach allows for a spatial and systematic evaluation of pasture suitability by integrating diverse environmental, infrastructural, and socio-economic factors into the analysis. The methodology includes a number of environmental factors, socioeconomic factors, and infrastructural indicators. In the GIS context, all criteria were standardized, weighted using the Analytic Hierarchy Process (AHP), and combined using a weighted linear combination. This method makes it possible to identify priority grazing zones for various seasons and offers a spatially explicit evaluation of pasture suitability.

A combination of multicriteria decision analysis and expert knowledge analysis was applied to ensure the relevance of the methodological approach. The general procedure for land suitability evaluations follows several steps (Fig. 4):

Define Objectives:
Establish the project's primary goal and specific objectives.

Select Criteria:
Determine the criteria and factors relevant to pasture suitability, drawing from both literature and on-the-ground expert consultations. During the process, five specialists were consulted, including one pasture management specialist and four local pasture users in the Ak-Talaa district. Their expertise made it possible to guarantee that the elements chosen appropriately represented regional ecological circumstances and actual management difficulties.

Standardize Criteria:
This step involved normalizing selected criteria such as natural hazards and slope to a common scale, enabling effective integration within the GIS-based analysis.

Criteria weights:
The AHP was used to rank and assign weights to the criteria. The weights and rank of each criterion directly influence the final analysis by determining the relative importance of each factor in the overall suitability assessment.

Weighted overlay:
The criteria layers were integrated into a GIS environment to produce a suitability map. This process involved overlaying raster layers of selected criteria. The output is a map visually representing varying suitability for grazing across the study area.

Validation:
This last step involves validation of resulted map through field surveys and expert consultation.

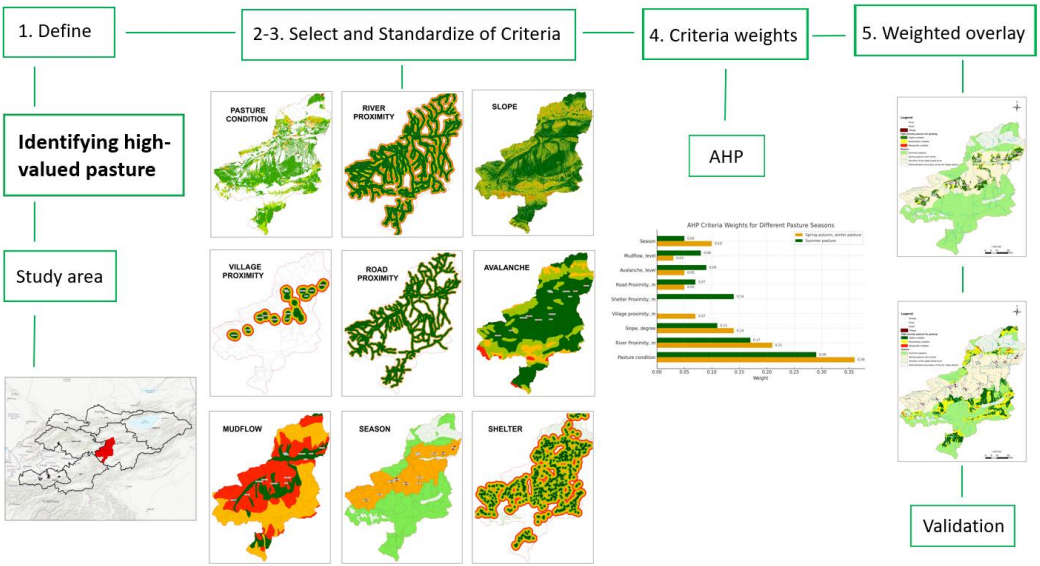


Figure 4: Framework of the suitability model

The criteria selection process identifies and chooses specific relevant and essential factors for evaluating a particular objective, such as the suitability and degradation of pasture areas. These criteria are the basis for analysis and decision-making within the GIS and MCDA framework.

Eight factors based on literature and experts' knowledge on the ground were identified and used for the suitability analysis in this research.

Various environmental and social data are used to define the value of pastures. The sources and types of data are summarized in Table 1.

Table 1: Datasets used for defining the value of pastures

Data	Units, resolution	Resource	Year
Aster Global Digital Elevation model V003	30 m	EarthData DOI10.5067/ASTER/AST_L1A.003	2021
Boundary of Ak-Talaa district	ha	"State Institution 'Cadastre' under the State Agency for Land Resources under the Cabinet of Ministers of the Kyrgyz Republic"	2025
Pasture condition	ha	Pasture geodatabase	2021

Internal boundaries of pastures: • Season	ha	Department of pastures and livestock breeding, Ministry of Agriculture KR	2021
Road	m	Pasture geodatabase, Department of Pastures and livestock breeding	2021
River	m	Pasture geodatabase, Department of Pastures and livestock breeding	2021
Shelter	piece	Pasture geodatabase, Department of Pastures and livestock breeding	2021
Village	ha	Pasture geodatabase, Department of Pastures and livestock breeding	
Avalanche	ha	Water Resources Services KR	2019
Mudflow	ha	Water Resources Services KR	2019

To support decision-making, the AHP was employed, a methodology based on paired comparisons that uses expert judgment to derive priority scales (Saaty,2008). Initially, all criteria were standardized to a uniform scale to ensure comparability. Subsequently, AHP was used to assign weights to these criteria based on their relative importance, determined through pairwise comparisons. The reliability of these comparisons was verified by calculating a consistency ratio.

Categorical standardization was employed instead of continuous standardization methods such as Min-Max. This approach involves reclassifying continuous data into discrete categories based on predefined ranges. The reasons behind selecting categorical standardization over continuous are:

- **Control over classification:** Exact ranges can be defined, allowing for assigning suitability values based on expert knowledge or specific criteria.
- **Ease of interpretation:** Results are easier to understand and interpret as each category represents a specific suitability class.
- **No linear relationships:** The data are not assumed to have linear relationships.

However, the limitations of this approach were also considered, such as the potential oversimplification of data by forcing it into discrete categories. Despite this, categorical standardization ensures that the suitability analysis reflects the specific criteria for this project.

Therefore, data were reclassified into discrete suitability categories based on FAO's land suitability assessment for grazing livestock and used consistently across all criteria (Blair-Rains et al.,1991). This eliminated the need for normalization as the data were already on a relative scale reflecting their importance, making them directly usable in the weighted overlay analysis. This approach categorized land suitability into four levels, with points corresponding to the suitability level of each specific land property, as shown in Table 2.

Table 2: The suitability level points of each specific land (Blair-Rains et al., 1991)

Land suitable class	Land suitability in category	Value
S1 - Highly suitable	Land without significant limitations.	1.00
S2 - Moderately suitable	Land that is suitable but has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land	0.75
S3 - Marginally suitable	Land with limitations so severe that benefits are reduced and the inputs needed to sustain production are increased so that this cost is only marginally justified	0.50
N4 – Not suitable	Land that cannot support the land use on a sustained basis or land on which benefits do not justify necessary inputs	0.25

Based on expert knowledge and relevant literature (Khazieva et al.,2022; Undeland,2005), specific criteria were established for winter and summer pastures to reflect seasonal variations in pasture requirements. Table 3 (spring- autumn, winter) and Table 4 (summer) are presented the selected criteria parameters for each suitability class.

Table 3: Spring- autumn, winter pasture suitability classes

Criteria	S1 - Highly suitable	S2-Moderately suitable	S3 -Marginally Suitable	N -Not suitable
Village Proximity, m	2000	3000	4000	5000
Pasture condition	Clean pasture	Stony pasture	Bush pasture	Swampy pasture
Slope, degree	0°-15°	15°-30°	30°-45°	45°≤
Season	Spring- autumn, winter pasture			
River Proximity, m	1000	1500	2000	2500
Road Proximity, m	800	1000	1200	1400
Avalanche, level	1	2	3	4
Mudflow, level	1	2	3	4

Table 4: Summer pasture suitability classes

Criteria	S1 - Highly suitable	S2-Moderately suitable	S3 -Marginally Suitable	N -Not suitable
Pasture condition	Clean pasture	Stony pasture	Bush pasture	Swampy pasture
Slope, degree	0°-15°	15°-30°	30°-45°	45°≤
River Proximity, m	1500	2000	2500	3000
Shelter Proximity, m	1000	2000	3000	4000

Road Proximity, m	1000	2000	3000	4000
Avalanche, level	1	2	3	4
Mudflow, level	1	2	3	4
Season	Summer pasture			

The AHP was employed to assign weights to each criterion based on their relative importance. This structured technique involves several key steps:

Construct pairwise comparison matrix: A pairwise comparison matrix was constructed to evaluate the relative importance of each criterion. This matrix compares each pair of criteria using a scale from 1 to 9, where 1 indicates equal importance, and 9 indicates extreme importance of one criterion over the other (Saaty,2008).

Normalization and weight calculation: Each element was divided by the total of its columns to normalize the aggregated matrix. The rows of the normalized matrix were then averaged to determine the priority vector (weights) for each criterion.

Check consistency: The Consistency Ratio (CR) and Consistency Index (CI) were calculated to guarantee the validity of expert opinions. Only matrices with CR < 0.1 were considered acceptable; when inconsistencies beyond this threshold were considered unacceptable, corrections were done.

Weighted overlay: The calculated weights were applied in ArcGIS Pro 3.3.5 to perform a weighted overlay of the raster layers representing each criterion. To enable meaningful integration, all raster layers were categorized and scaled to a standard range (0–1). By combining these layers into a single output raster, the weighted overlay approach generated a cumulative suitable score for every grid cell. The produced map shows high-value grazing areas for focused management while showing local variations in pasture suitability.

2.3 Validation

The suitability map was assessed using field surveys and existing pasture data. A sensitivity analysis was conducted to assess the robustness of the results and the impact of varying criterion weightings.

- Validation using field data. Field validation was conducted using GPS-located sampling points randomly distributed across the Ak-Talaa district. Above-ground biomass at each site was measured during the peak growing season (June-August 2021) to compare observed pasture conditions with suitability classes projected by the AHP-MCDA model.
- Verification of the correlation coefficient between the data obtained through analysis and field data.
- To validate the field data, ten pasture users with knowledge of the pasture situation, large livestock herds, and grazing livestock on remote pastures were interviewed, confirming the accuracy of the study.

In terms of the robustness of the methodological approach, the correlation coefficient between the analysis data and field data was R2 = 0.82.

Information on grazing, biomass, and locations of the largest livestock concentrations was collected from 40 field observation points from 2019 to 2024.

3 Result

The analysis was conducted separately for summer and spring-autumn, winter pastures, allowing for a more nuanced understanding of the factors contributing to degradation across different seasons. The weighted overlay analysis combined these factors to produce composite suitability maps for both seasonal pastures, identifying areas that require immediate management attention and those more suitable for grazing (Table 5).

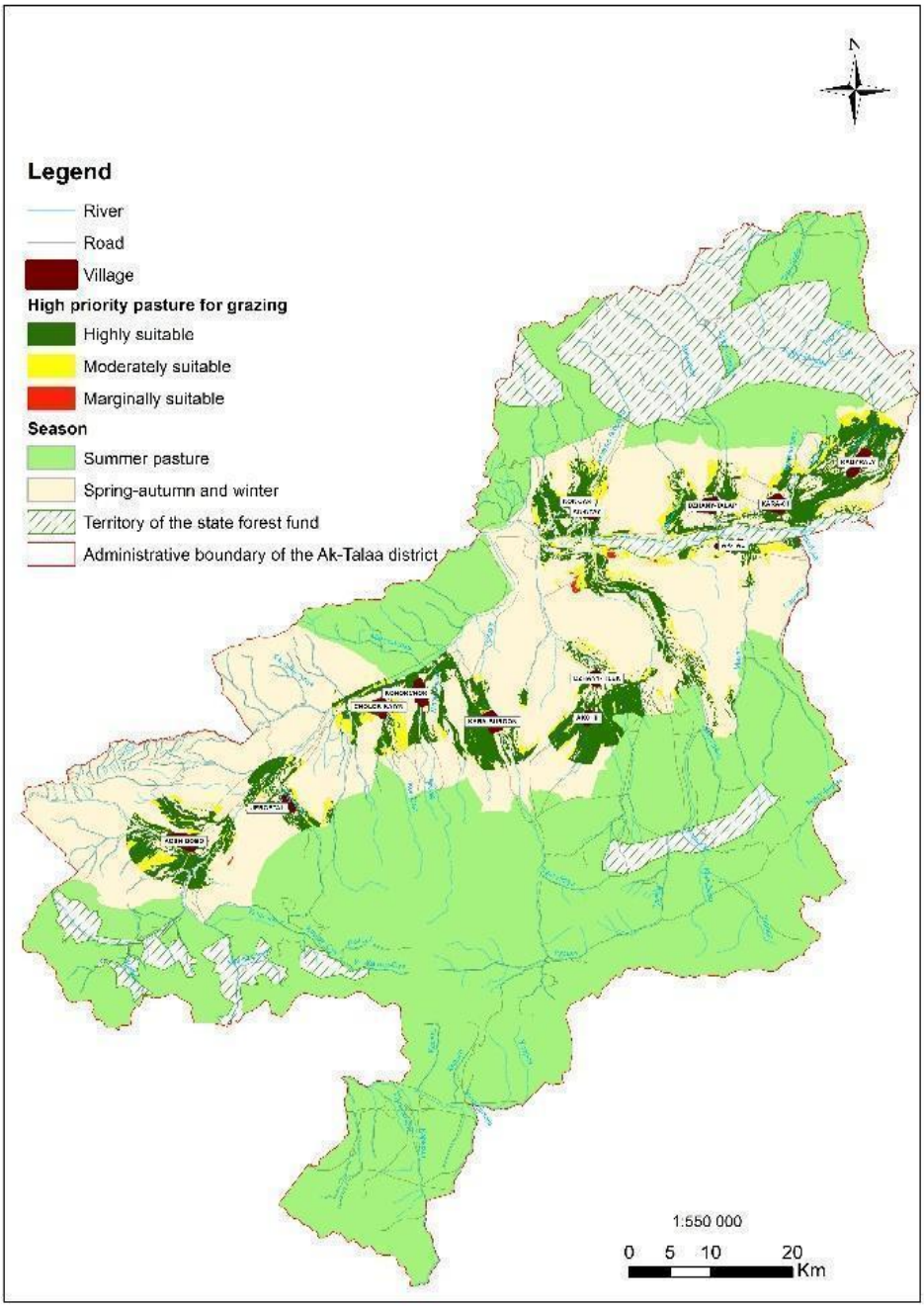
CR is 0,069 for spring- autumn, winter pasture, and Consistency ratio CR is 0,087 for summer pasture. Since both values are less than the threshold level of 0.1, the comparisons are considered consistent.

Table 5: Weights assigned to pasture suitability criteria

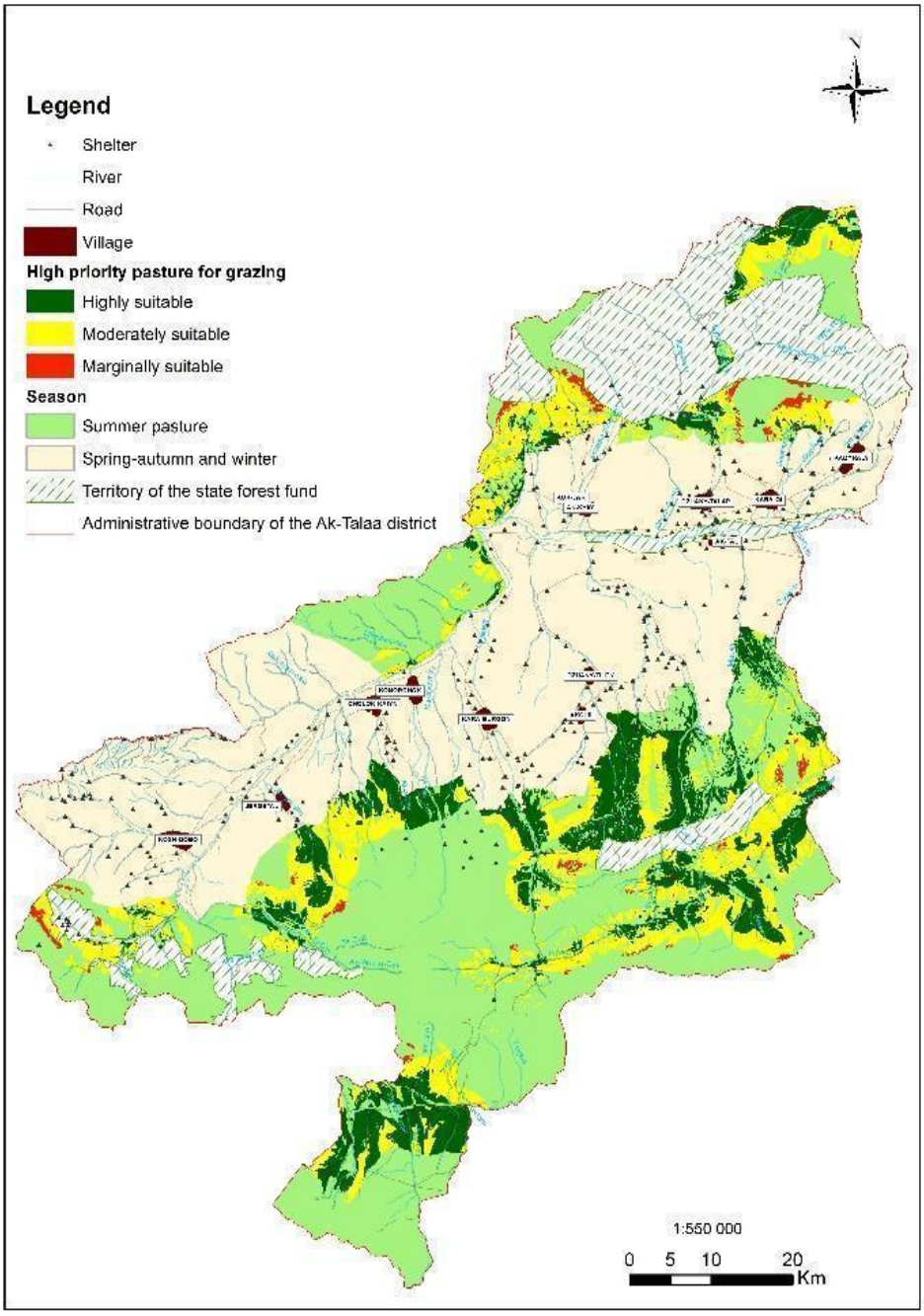
№	Criteria	Weight	
		Spring- autumn, winter pasture	Summer pasture
1	Pasture condition	0,36	0,29
2	River proximity, m	0,21	0,17
3	Slope, degree	0,14	0,11
4	Village proximity,m	0,07	
5	Shelter proximity, m		0,14
6	Road proximity, m	0,05	0,07
7	Avalanche, level	0,05	0,09
8	Mudflow, level	0,03	0,08
9	Season	0,10	0,05

The suitability classification map (Figure 5) categorizes the pastures into four levels of suitability: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N4). This map provides a clear visual representation of pasture distribution and quality across seasons, helping to identify areas with the highest potential for grazing and requiring more careful management due to their limitations

The land suitability model shows (Table 6) that 186645,49 hectares of the total pasture area assessed are classified as suitable for grazing. This includes 40981,24 hectares of highly suitable land for spring/autumn/winter pastures and 57010,59 hectares for summer pastures. The moderately suitable land comprises 11366,79 hectares for spring/autumn/winter pastures and 73093,45 hectares for summer pastures. These results underscore the importance of managing pasture use carefully to maximize the productivity of these high-value areas while avoiding overgrazing and degradation.


N
Legend
River
Road
Village
High priority pasture for grazing
Highly suitable
Moderately suitable
Marginally suitable
Season
Summer pasture
Spring-autumn and winter
Territory of the state forest fund
Administrative boundary of the Ak-Talaa district
1:550 000
0 5 10 20
Km

(a)



(b)

Figure 4: Suitability classification map for pasture (Ak-Talaa district): (a) Spring- autumn, winter pasture, (b) Summer pasture

Table 6: Area of the suitable class

Land suitable class	Spring-autumn and winter pasture area ha	Summer pasture area, ha
S1 - Highly suitable	40981,24	57010,59
S2 - Moderately suitable	11366,79	73093,45
S3 - Marginally suitable	233,66	3959,76
N4 – Not suitable	0	0
Total area, ha	52581,69	134063,8

The area classified as not suitable (N4) is 0 because glaciers, rock gardens, and other land types were excluded from the analysis, and only pasture contours were used.

Identifying high-value pastures is crucial for ensuring the sustainability of grazing practices in the Ak-Talaa district. As outlined in the AA's prospective 5-year development plans (2018-2022), the total pasture area is 353867 hectares, with a livestock population of 63182 UG (NSC,2024). The suitability analysis shows that 186654 hectares are suitable for grazing, emphasizing the need to balance grazing activity with the land's carrying capacity.

Moving forward, it will be essential to evaluate the pasture carrying capacity in more detail, considering not only the suitability of the land but also its ability to support livestock sustainably over time (Undeland, 2005). This approach will help prevent overgrazing and further degradation of the pasture ecosystem. Additionally, the results highlight the importance of continuous monitoring and adaptive management to address changing environmental conditions and maintain the productivity of high-value pastures (McCord & Pilliod, 2022).

4 Discussion and conclusion

Field validation included interviews with ten pasture users who had considerable knowledge of local pasture characteristics, big livestock herds, and remote pasture grazing habits, confirming the model's appropriateness results. The study found considerable geographical and seasonal variations in pasture suitability, indicating the joint influence of natural, biological, and anthropogenic variables on pasture ecosystem resilience.

The results revealed significant spatial and seasonal differences in pasture suitability, highlighting the combined influence of natural conditions and anthropogenic factors on the resilience of pasture ecosystems. The study results demonstrate that a significant portion of pastures retains high potential for sustainable use, provided appropriate management measures are implemented.

Differences in suitability reflect both the natural, ecological, and socioeconomic characteristics of the area. Summer pastures, despite their high natural productivity, are vulnerable to climate fluctuations, lack of infrastructure, and a shortage of seasonal campsites and water sources. Meanwhile, spring-autumn and winter pastures, located closer to settlements, experience higher pressure due to intensive overgrazing and infrastructure expansion, which contributes

to land degradation. This highlights the need to develop seasonally tailored management strategies: optimizing water supply, adapting to climate change, improving infrastructure on summer pastures, addressing economic and social constraints, and regulating grazing intensity and spatial distribution of pressures on year-round pastures. The obtained results contribute to the development of sustainable pasture management strategies by providing quantitative and spatially accurate data for local-level management decisions. The integration of GIS - MCDA with the AHP methodology and FAO criteria demonstrates an effective and replicable approach to assessing pasture potential in mountainous regions.

Increasing livestock numbers while maintaining a constant pasture area puts pressure on ecosystems and requires the implementation of effective pasture management mechanisms. In the future, this methodology could be expanded to include additional biophysical, climatic, and socioeconomic indicators, such as soil properties, seasonal vegetation productivity, climate variability, and market accessibility. This will improve the accuracy of pasture suitability modeling, enable long-term monitoring, and support adaptive management aimed at preserving the ecological and economic sustainability of Central Asian pasture landscapes.

During the preparation of this manuscript the author(s) used AI tool(s) (ChatGPT) to improve readability and language. After using this/these tool(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the manuscript.

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