NATIONAL UNIVERSITY OF MONGOLIA
SCHOOL OF ART AND SCIENCES
DEPARTMENT OF GEOGRAPHY

Geographical Issues

Газарзүйн Асуудлууд

Volume 26 (01) *ISSN: 2312-8534* *2026*

Ulaanbaatar

Identifying Land Suitability for Nomadic Pastoralism using Geospatial Techniques and Multi-Criteria Decision Analysis (MCDA)

Perliimaa Gantumur[1], Bazarkhand Tsegmid[1]*, Kamal Pandey[2], Mungunchimeg Nasanbat[3]

[1]*Department of Geography, School of Arts and Sciences, National University of Mongolia, Ulaanbaatar 210646, Mongolia*

[2]*Indian Institute of Remote Sensing, Indian Space Research Organisation, Uttarakhand 248001, India*

[3] *Information and Research Institute of Meteorology, Hydrology and Environment, Ulaanbaatar 15160, Mongolia*

*Corresponding author: bazarkhand_ts@num.edu.mn

Received:2025.06.03
Revised: 2025.09.11
Accepted: 2025.09.14

Abstract

This study evaluates the spatial suitability of land for nomadic pastoralism across two distinct seasonal periods: winter–spring and summer–autumn. Nomadic pastoralism is a cornerstone of Mongolia's rural livelihood system, but its sustainability is increasingly challenged by pasture degradation, climatic variability, and socio-economic pressures. Since pasture quality and accessibility fluctuate significantly between seasons, identifying suitable grazing areas is critical for ensuring both ecological resilience and herder well-being. To capture these dynamics, seven environmental and socio-economic factors were selected for each season and analyzed using a geographic information system (GIS)–based multi-criteria decision analysis (MCDA). Factor selection followed the methodological guidelines for pasture suitability assessment issued by the Agency of Land Administration and Management, Geodesy and Cartography (ALAMGaC), while additional determinants reflecting herder mobility and traditional grazing practices were incorporated to refine the evaluation framework. The results reveal distinct seasonal contrasts. During the winter–spring season, 11.26% of the study area was identified as unsuitable for grazing, 18.02% as less suitable, 46.37% as moderately suitable, and 24.35% as highly suitable. In contrast, summer–autumn conditions produced a less favorable distribution, with 23.83% unsuitable, 30.66% less suitable, 30.22% moderately suitable, and only 15.29% highly suitable. These differences emphasize the influence of climatic and ecological seasonality on pasture productivity and herding strategies. The findings suggest that sustainable pasture management requires not only an understanding of spatial heterogeneity but also season-specific planning. Such an approach can provide valuable insights for policymakers, land managers, and local herding communities seeking to maintain the viability of nomadic pastoral systems under changing environmental and socio-economic conditions.

Keywords: *Nomadic pastoralism, Land suitability assessment, Multi-criteria decision analysis (MCDA), Seasonal variability, Grassland of Bulgan province*

Нүүдлийн бэлчээрийн газрын тохиромжтой байдлыг орон зайн олон шалгуурт шийдвэр гаргалтын шинжилгээ (MCDA)-гээр үнэлэх нь

© Гантөмөр Пэрлиймаа[1], Цэгмид Базарханд[1], Камал Пандей[2], Насанбат Мөнгөнчимэг[3]

[1]*Газарзүйн тэнхим, Шинжлэх Ухааны Сургууль, Монгол Улсын Их Сургууль, Улаанбаатар 210646, Монгол Улс*

[2]*Энэтхэгийн зайнаас судлалын хүрээлэн, Энэтхэгийн Сансрын Судалгааны Байгууллага, Уттаракханд 248001, Энэтхэг Улс*

[3]*Хөдөө Аж Ахуйн Цаг Уурын Судалгааны Хэлтэс, Ус Цаг Уур, Орчны Судалгаа, Мэдээллийн Хүрээлэн, Улаанбаатар 15160, Монгол Улс*

*Холбоо баригч зохиогч: bazarkhand_ts@num.edu.mn

Хүлээн авсан: 2025.06.03
Засварласан: 2025.09.11
Зөвшөөрөгдсөн: 2025.09.14

Хураангуй

Энэхүү судалгааны ажил нь нүүдлийн мал аж ахуйд тохирох бэлчээрийн газрын улирлын онцлогийг харгалзан, өвөл–хавар болон зун–намрын хоёр үе шатанд газрын тохиромжтой байдлыг үнэлсэн болно. Нүүдлийн мал аж ахуй нь Монгол Улсын хөдөө орон нутгийн амьжиргааны тулгуур хэлбэр боловч бэлчээрийн доройтол, уур амьсгалын хэлбэлзэл, нийгэм-эдийн засгийн дарамтаас үүдэн тогтвортой байдал нь улам бүр сорилттой тулгарч байна. Бэлчээрийн чанар, хүртээмж улирлаас шалтгаалан эрс ялгаатай байдаг тул тохиромжтой газар нутгийг тодорхойлох нь экосистемийн тогтвортой байдал болон малчдын амьжиргааг хангахад чухал ач холбогдолтой. Судалгаанд улирал бүрт нийт долоон байгаль орчны болон нийгэм-эдийн засгийн хүчин зүйлийг сонгон авч, газарзүйн мэдээллийн систем (GIS)–д суурилсан олон шалгуурт шийдвэрийн шинжилгээ (MCDA)–ний аргаар үнэлгээг хийсэн. Хүчин зүйлийн сонголтыг Газар зохион байгуулалт, геодези, зураг зүйн газрын (ГЗБГЗЗГ) бэлчээрийн тохиромжтой байдлыг үнэлэх аргачлалын зааврын дагуу хийж, уламжлалт нүүдэл, малчдын хөдөлгөөний онцлогийг тусган нарийвчилсан болно. Үр дүнгээс харахад улирлын ялгаа тод илэрч байна. Өвөл–хаврын улиралд нийт судалгааны талбайн 11.26% тохиромжгүй, 18.02% бага тохиромжтой, 46.37% дунд зэрэг тохиромжтой, харин 24.35% нь өндөр тохиромжтой гэж үнэлэгдсэн бол зун–намрын улиралд 23.83% нь тохиромжгүй, 30.66% бага тохиромжтой, 30.22% дунд зэрэг тохиромжтой, 15.29% нь өндөр тохиромжтой байв. Эдгээр ялгаа нь уур амьсгал, экологийн улирлын нөлөө бэлчээрийн бүтээмж, малчдын ашиглалтын стратегид хүчтэй нөлөөлдөг болохыг харуулж байна. Судалгааны дүнгээс үзэхэд тогтвортой бэлчээрийн менежмент нь зөвхөн орон зайн ялгааг ойлгохоос гадна улиралд нийцсэн төлөвлөлт шаардлагатайг онцолж байна. Ийм хандлага нь бодлого боловсруулагчид, газрын менежерүүд, орон нутгийн малчдад нүүдлийн мал аж ахуйн тогтвортой байдлыг хангах үнэтэй ойлголт өгөх боломжтой юм.

Түлхүүр үгс: *Нүүдлийн мал аж ахуй, Газрын тохиромжтой байдлын үнэлгээ, Олон шалгуурт шийдвэр гаргалтын шинжилгээ (MCDA), Улирлын хэлбэлзэл, Булган аймгийн бэлчээр*

©Зохиогчийн оруулсан хувь нэмэр: **Г.Пэрлиймээ, Ц.Базарханд:** Онолын үндэслэл, үндсэн бичвэр, өгүүллийн эх бэлтгэл, үр дүнгийн хяналт; **К.Пандей, Н.Мөнгөнчимэг**: Аргазүй боловсруулалт, зураглал боловсруулалт, үр дүнгийн хяналт

Introduction

Approximately 70% of Mongolia's territory is covered by pasturelands, which form the foundation of the country's traditional nomadic pastoralism (Agency of Land Administration and Management, 2022; Mungunchimeg et al., 2024). In recent years, competition over land use has intensified, as multiple stakeholders—including herders dependent on pasturelands and actors pursuing alternative land uses such as mining, infrastructure development, and urban expansion—vie for limited land resources (Rao et al., 2015; Yan et al., 2023). Understanding the spatial suitability of land for pastoralism is therefore crucial to anticipate potential conflicts, inform sustainable land management, and safeguard the livelihoods of herding communities (Nyamaa et al., 2024).

Previous assessments of pastureland suitability in Mongolia have primarily focused on evaluating forage availability and livestock-specific carrying capacity across different seasons (Agency of Land Administration and Management, 2015). However, these studies often overlook critical socio-economic and environmental factors that influence pastoral decision-making and mobility. To address this gap, the present study evaluates land suitability for nomadic pastoralism across two seasonal periods—winter–spring and summer–autumn—integrating socio-economic variables such as proximity to settlements and roads, as well as the density of winter herder households (Enkhjargal, 2022). Environmental constraints, including the frequency of drought and dzud (severe winter disasters), winter air temperatures, seasonal pasture boundaries, and overall pasture carrying capacity, are also incorporated, as they strongly affect the viability of pastoral livelihoods (Mungunchimeg et al., 2024).

The results of this study will provide spatially explicit information on the suitability of pasturelands for nomadic pastoralism in Mongolia, offering valuable guidance for policymakers, land managers, and local communities. Such insights can support sustainable pasture management, mitigate land use conflicts, and enhance the resilience of pastoral livelihoods to environmental and socio-economic pressures. Moreover, the study provides a scientific basis for developing targeted interventions to optimize land allocation while preserving Mongolia's unique pastoral heritage (Yan et al., 2023).

This study employs geospatial techniques in combination with Multi-Criteria Decision Analysis (MCDA) to assess land suitability. MCDA enables the integration of diverse criteria, weighting their relative importance, and producing a composite suitability map (Malczewski, 2006; Balew et al., 2022; Legese et al., 2025). Geographic Information Systems (GIS) are used to manage spatial data layers, including land cover, topography, climate, and socio-economic indicators, facilitating a robust and replicable assessment framework (Legese et al., 2025).

Bulgan province, located in the central steppe region of Mongolia, is characterized by a high risk of pasture degradation due to both environmental and anthropogenic pressures (Dorjsuren et al., 2021). The condition of its pastures is influenced by multiple factors, including aridity indices, normalized vegetation indices, precipitation patterns, and human activities. In 2006, approximately 14.2% of Bulgan's pasturelands were classified as lightly degraded, 1.7% as moderately degraded, and 0.32% as severely degraded. By 2019, these degradation levels had increased, with certain areas experiencing up to a 30% decline in pasture condition (Enerel & Mandakh, 2020; Li et al., 2022).

Given this context, assessing the suitability of pasturelands in Bulgan province is particularly important. Such an evaluation can provide critical insights for mitigating land use conflicts, promoting sustainable pasture management, and supporting socio-economic development while maintaining environmental resilience. Consequently, Bulgan province was selected as the study area to examine land suitability for nomadic pastoralism, considering both seasonal variations and socio-environmental factors.

Study area

The study focuses on the southern part of Bulgan Province (Bulgan Aimag), one of Mongolia's 21 provinces, which is recognized for its historical significance, diverse topography, and agricultural productivity (Enerel & Mandakh, 2020; Li et al., 2022). The province encompasses a complex landscape of mountains, rolling steppe, river valleys, and forest-steppe mosaics, creating a variety of microenvironments suitable for both livestock grazing and limited crop cultivation. This ecological diversity has supported traditional nomadic pastoralism for centuries, making Bulgan a representative area for studying pastureland suitability (Jargalsaikhan & Gombosuren, 2021).

The study area covers approximately 2,259,821.85 hectares and is geographically situated in central Mongolia (48.25°N, 103.55°E), within a transitional forest-steppe zone characterized by fertile soils, moderate slopes, and an abundance of natural resources (Enkhjargal, 2022). The climate is typically continental, with cold, dry winters and warm summers, which significantly influences seasonal pasture availability, livestock mobility, and herder decision-making. Environmental challenges, including periodic droughts, occasional dzud events, and localized land degradation, further shape land use patterns in the region (Figure 1).

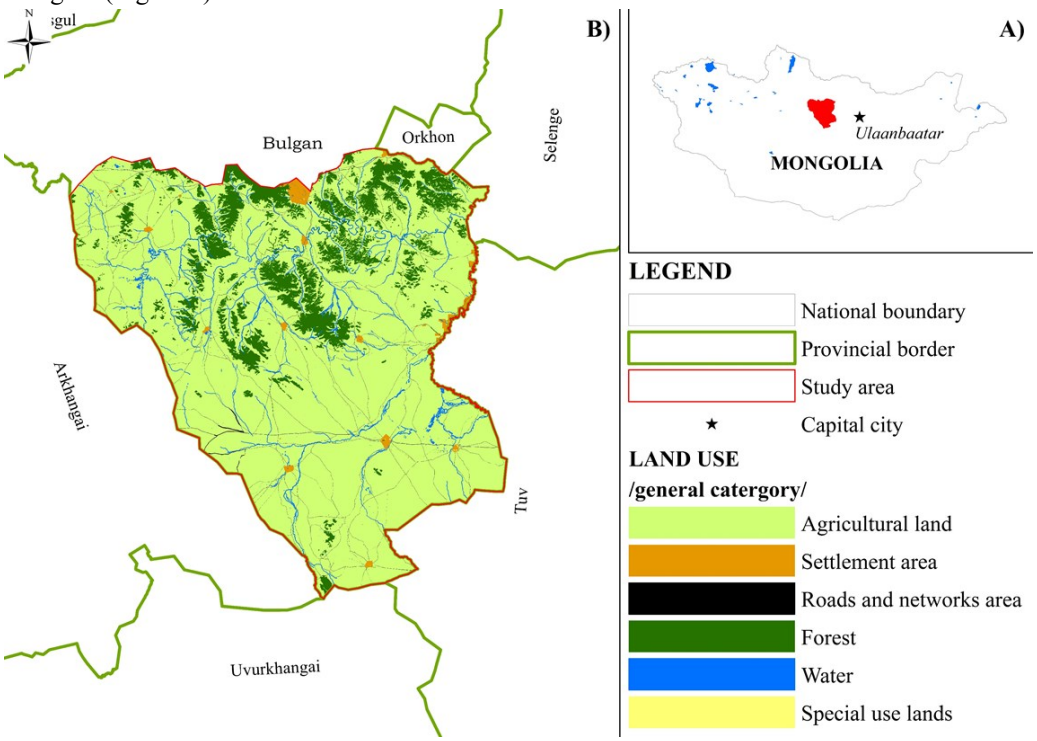

Figure 1. Study Area A. Research location and land use status map of southern Bulgan Province. B. Land use distribution in the study area. Land use is categorized into agricultural land, forested areas, and other land uses—including settlements, infrastructure, and water bodies—based on data from the Agency of Land Administration and Management (2020).

Land use in the study area is dominated by agricultural and pasturelands, which collectively account for the majority of the territory. According to the Agency of Land Administration and Management (2020), agricultural land represents 84.87% of the total area, forested areas cover 12.67%, and other land uses—including settlements, infrastructure, and water bodies—make up 2.46%. These patterns reflect the central role of pastoralism in the local economy and highlight the potential for competition over land use among herders, conservation areas, and emerging development activities.

The combination of ecological diversity, socio-economic dependence on livestock, and exposure to environmental constraints makes southern Bulgan Province an ideal case study for evaluating land suitability for nomadic pastoralism. Assessing the spatial distribution of suitable pasturelands in this region can provide critical insights for sustainable land management, conflict mitigation, and the long-term resilience of traditional pastoral systems in Mongolia (Mungunchimeg et al., 2024).

Materials and Methodology

Data sources and pre-processing: In the research, 14 data sets belonging to 2 seasons: satellite data (RS data), qualitative and statistical data, and thematic maps were collected from official sources and prepared for analysis.

The Normalized Difference Vegetation Index (NDVI) is a widely used indicator for monitoring vegetation status and land cover dynamics (Zhao & Qu, 2024). This study utilizes Sentinel-2 imagery from Google Earth Engine (GEE) to calculate the average NDVI during the summer months (June, July, and August) over the past five years (2020–2024). The Sentinel-2 dataset, provided by the European Space Agency (ESA), offers high resolution multi-spectral imagery, which is ideal for vegetation analysis. The analysis employs the Sentinel-2 Surface Reflectance (S2_SR) dataset, which corrects for atmospheric effects and improves the accuracy of spectral indices. The NDVI values from all selected images across the five-year period are aggregated to compute a mean summer NDVI.

Air temperature data from the last 15 years was used from NASA POWER (Prediction Of Worldwide Energy Resources) that is a data service that provides meteorological and climatological datasets derived from satellite observations and reanalysis models. To estimate the spatial distribution of air temperature across the study area, the Inverse Distance Weighting (IDW) method and DEM-based elevation transformation techniques were utilized to adjust temperature values to sea level based on measurements taken at various altitudes. The DEM data are from the ALOS PALSAR 12.5 m resolution elevation dataset in the GEE. The standard lapse rate formula, which accounts for the decrease in temperature with increasing altitude, was applied for this adjustment.

Specifically, the International Standard Atmosphere (ISA) lapse rate was used, which approximates a temperature decrease of 2°C (3.5°F) per 1000 feet or 6.5°C per 1000 meters of altitude gained. Formula 1 for Converting Air Temperature to Sea Level Temperature (Sheridan, 2010):

$$TSL=T+(L\times h) \quad (1)$$

Where, TSL = Temperature at sea level (°C), T = Measured temperature at altitude (°C), L = Lapse rate (°C per meter) (-0.0065°C/m or -6.5°C/km), h = Altitude above sea level (meters)

Qualitative and statistical data, along with thematic maps, were obtained from the Information and Research Institute of Meteorology, Hydrology, and Environment (IRIMHE), as well as the Agency of Land Administration and Management, Geodesy, and Cartography (ALAMGaC) in Mongolia. After processing, these were transformed into 12.5 m × 12.5 m raster layer in ArcGIS 10.8.

The workflow integrates remote sensing data, qualitative and thematic data, and multi-criteria decision-making (AHP) within GIS. By weighting different natural and socio-economic factors, it generates seasonal suitability maps for nomadic pastoralism that guide decision-makers in sustainable nomadic livestock management (Figure 2).

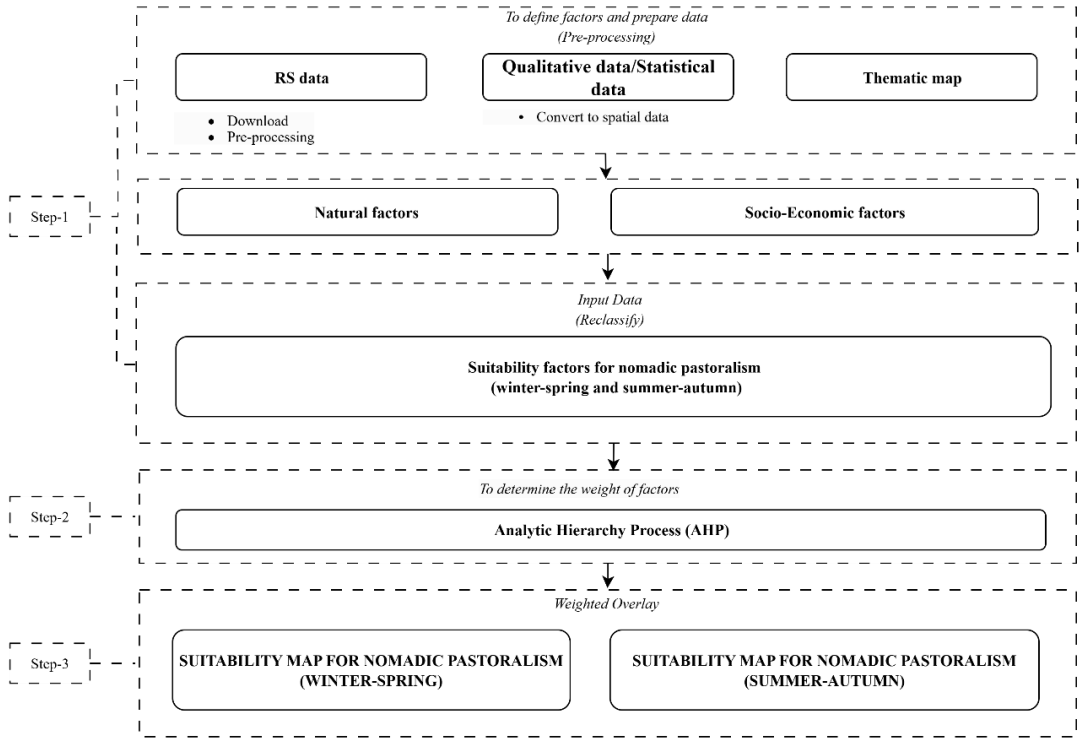

Figure 2. The flowchart of analytical steps of the research

Multi-Criteria Decision Analysis: We conducted the selection of evaluation factors, determination of index weights, factor assignment, calculation of evaluation unit scores, and classification of suitability levels to construct a multi-criteria decision analysis (MCDA) framework (Akyol, Kaya, & Alkan, 2016) for assessing land suitability for nomadic pastoralism.

Selection of evaluation factors: When evaluating the suitability of nomadic pastoralism, two distinct seasons were considered winter-spring and summer-autumn, its factors based on land use characteristics, nomadic lifestyle and methodological guidelines for pasture suitability assessment published from ALAMGaC (Agency of Land Administration and Management, 2020), For each season, seven factors were selected, resulting in a total of 14 factors, all evaluated across five grades (Table 1).

Table 1. Evaluation factors and weights of land suitability for nomadic pastoralism (winter-spring)

Factor	Weight	Grading and assignment				
		1	3	5	7	9
Air temperature, °C (winter average)	0.124	> (-18)	(-17) -(-18)	(-16) -(-17)	(-15) -(-16)	< (-15)
Dzud frequency	0.161	Very High	High	Moderate	Low	Very Low
Pasture carrying capacity, %	0.208	>400% and no pasture resources	300-400%	200-300%	100-200%	well-suited (<100%)
Seasonal pasture boundary	0.249	Non-pasture	out	-	in	-
Distance from main roads, km	0.057	>15	8-15	5-8	3-5	<3

Distance from town, km	0.057	>20	15-20	10-15	5-10	<5
Density of the herding house	0.143	Very High (>0.4)	High (0.25-0.4)	Moderate (0.1-0.25)	Low (0.05-0.1)	Very Low (<0.05)
CR	**0.038**					

Table 2. Evaluation factors and weights of land suitability for nomadic pastoralism (summer-autumn)

Factor	**Weight**	**Grading and assignment**				
		1	**3**	**5**	**7**	**9**
NDVI	0.194	<0	0.0-0.03	0.03-0.3	0.3-0.5	>0.5
Distance from river and lake/km	0.258	>8	6-8	4-6	2-4	<2
Drought frequency	0.063	>80%	50-80%	30-50%	10-30%	<10%
Pasture carrying capacity	0.17	>400% and no pasture resources	300-400%	200-300%	100-200%	well-suited (>100%)
Seasonal pasture boundary	0.22	Non-pasture	out	-	in	-
Distance from main roads, km	0.048	>15	8-15	5-8	3-5	>3
Distance from town, km	0.047	>20	15-20	10-15	5-10	>5
CR	**0.045**					

Weight determination: In this study, the Analytic Hierarchy Process (AHP) was applied to determine weights to the evaluation factors, and a hierarchical structure comprising the target, criterion, and index levels was constructed for the selected factors (Saaty, 1977). Following expert consultation, a 1–9 scale of importance was applied to evaluate the relative priority of indicator pairs, and the results were organized into a comparison matrix. The weights of the evaluation factors were then derived using the AHP Online System (AHP-OS) (Goepel, 2018).

Factor assignment: The assignment of factors was carried out using various methods depending on their attributes. After checking several NDVI classification, B.N Holben's classification was considered suitable in the case (Holben, 1986). Information and Research Institute of Meteorology, Hydrology, and Environment defines dzud frequency, drought frequency and pasture carrying capacity by their own scientific methods every year . We developed classification of main road, town and herders' house based on their density and distribution. The distance from rivers and lakes was classified according to the average distance livestock travel to access water. Seasonal pasture boundaries are determined according to the pasture utilization practices of herders, as recorded by ALAMGaC. Ultimately, the factors were reclassified into five levels, from high to low, and corresponding scores of 9, 7, 5, 3, or 1 were allocated using spatial analysis tools in ArcGIS (Balew et al., 2022; Legese et al., 2025).

Calculation of total score of evaluation unit: The total score of each evaluation unit was obtained by applying the exponential weighted model (Qiu et al., 2014) according to Equation 2.

$$S = \sum_{i=1}^{m} \sum_{k=1}^{n} (W_k * \varepsilon_k) * E_i \quad (2)$$

Where, S- the final sum or total value, W_k the indicator value of factor k, ε_k- the weight of factor k, E_i- the weight of principal i

Result and Discussion

Collection of factors for the land suitability of nomadic pastoralism: The assessment of land suitability for nomadic pastoralism in southern Bulgan Province was conducted by integrating both natural and socio-economic factors across two seasonal periods: winter–spring and summer–autumn. Natural factors considered included air temperature, drought frequency, normalized difference vegetation index (NDVI), distance from rivers and lakes, and pasture carrying capacity. Socio-economic factors incorporated seasonal pasture boundaries, distance from main roads, proximity to settlements, and the density of herder households. The spatial patterns of these factors, as illustrated in Figure 3, reveal significant seasonal and spatial variability in land suitability across the study area.

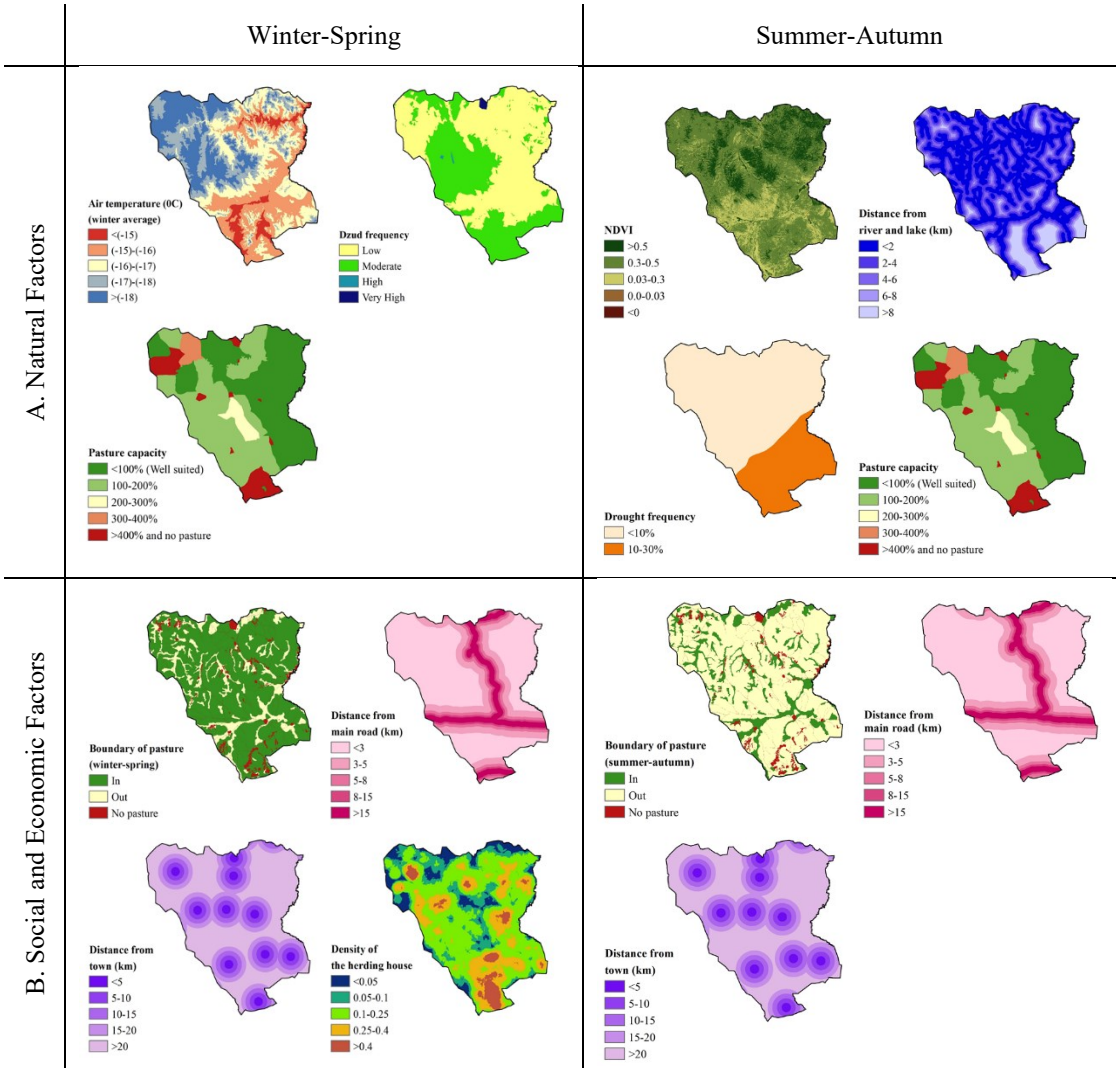

Figure 3. Collection of factors for the land suitability of nomadic pastoralism in Bulgan Province, Central Mongolia A. Natural Factors B. Social and Economic Factors

During the winter–spring period, air temperatures in the southern and western portions of the province were observed to be lower than –16°C, which may impose thermal stress on livestock and reduce forage availability. Correspondingly, areas experiencing frequent dzud events were concentrated in the southern and southwestern zones, indicating higher environmental constraints for winter grazing. Pasture carrying capacity maps revealed that the central and northern parts of the study area were generally well-

suited (<100% capacity), while the southern margins exhibited overgrazing and low forage availability (>400% of capacity or no pasture). These natural limitations were complemented by socio-economic constraints, particularly the distance from main roads and towns. Most high-density herder households were located in central and north-central areas, suggesting that livestock management practices are concentrated where access to infrastructure and services is better.

In the summer–autumn period, NDVI values indicated improved vegetation productivity in the central and northern regions, supporting seasonal pasture expansion. Drought frequency remained a limiting factor in the southern portions, although it was less severe than in winter. Pasture boundaries during this period expanded into previously marginal areas, reflecting the traditional mobility of herders in response to seasonal forage availability. Socio-economic factors such as distance from roads and towns continued to influence the spatial distribution of grazing activity. Areas with lower accessibility (>15 km from roads or towns) were sparsely populated, resulting in underutilized pasture resources.

Overall, the integration of natural and socio-economic factors highlighted a complex spatial pattern of suitability. Central and northern regions consistently exhibited favorable conditions for nomadic pastoralism, with optimal combinations of forage availability, moderate environmental stress, and proximity to infrastructure. In contrast, the southern and southwestern areas faced higher environmental constraints and lower accessibility, limiting their suitability. Seasonal differences further emphasized the importance of temporal mobility in pastoral systems, with herders shifting between winter and summer pastures to optimize resource use.

These findings demonstrate that land suitability for nomadic pastoralism in Bulgan Province is strongly influenced by the interplay between environmental factors, such as temperature, drought, and pasture productivity, and socio-economic variables, including settlement patterns, infrastructure proximity, and herd density. The results provide a spatially explicit foundation for informed pasture management, sustainable land allocation, and mitigation of potential land use conflicts within the province.

Distribution maps of suitability for nomadic pastoralism: Seasonal distribution of land suitability for nomadic pastoralism, illustrating how suitable areas shift across spring, summer, autumn, and winter due to variations in vegetation, water availability, and climatic conditions (Figure 4).

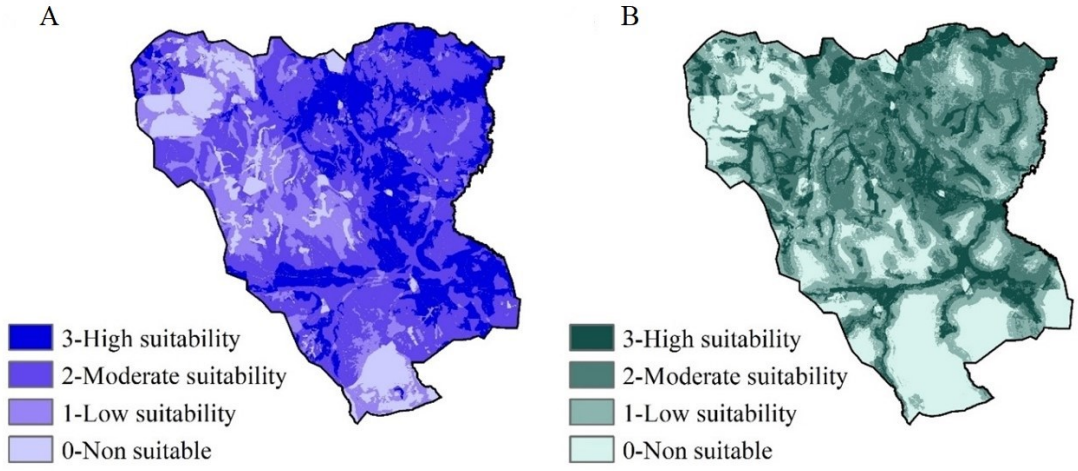

Figure 3. Distribution maps of suitability for nomadic pastoralism (A. Winter-spring and B. Summer-autumn)

The spatial distribution of land suitability for nomadic pastoralism exhibits distinct and pronounced seasonal variation (Figure 4). During the winter–spring period (Figure 4A), a relatively large proportion of the study area is classified as highly suitable (class 3), particularly within the central and southern

zones. This pattern reflects the availability of critical winter forage resources and the relative proximity of pastures to herder households and supporting infrastructure, which facilitates effective livestock management. Areas of moderate suitability (class 2) are more widely dispersed across the landscape, whereas low suitability (class 1) and non-suitable (class 0) zones are comparatively limited, indicating that the majority of the terrain retains functional grazing capacity during this season. In contrast, the summer–autumn period (Figure 4B) demonstrates a substantial reduction in highly suitable areas, with a considerable portion of the territory shifting to moderate or low suitability. This seasonal decline in land suitability can be attributed to multiple environmental factors, including increased drought frequency, decreased pasture productivity, and heightened ecological stress associated with higher temperatures and limited water availability. These results highlight the dynamic nature of pastoral resources and underscore the importance of seasonal planning in sustaining nomadic grazing practices.

Table 3. Results of suitability evaluation for nomadic pastoralism in the study area

Suitability classification	Winter-Spring				Summer-Autunm			
	0	1	2	3	0	1	2	3
Area (ha)	25425	407176	1047569	549961	538279	692627	682652	345322
Percent (%)	11.26%	18.02%	46.37%	24.35%	23.83%	30.66%	30.22%	15.29%

The land suitability assessment for nomadic pastoralism revealed notable seasonal variations across the study area. During the winter–spring season, 11.26% of the land was classified as unsuitable, 18.02% as having low suitability, 46.37% as moderately suitable, and 24.35% as highly suitable for grazing. These conditions correspond to the availability of early spring vegetation and accessible water sources in valleys and near rivers. In contrast, during the summer–autumn season, unsuitable and low suitability areas increased markedly to 23.83% and 30.66%, while moderately and highly suitable areas decreased to 30.22% and 15.29%, respectively. This decline reflects seasonal reductions in forage quality and water availability, highlighting the dynamic nature of land suitability and the importance of temporal planning for pastoral activities.

Seasonal Land Suitability for Nomadic Pastoralism: The maps reveal that areas suitable for pastoral activities are not uniform across the landscape, but rather fluctuate in accordance with seasonal changes, environmental conditions, and resource availability (Balew et al., 2022). In spring, regions located near rivers, wetlands, and valley bottoms exhibit higher suitability due to the early onset of vegetation growth and access to reliable water sources. These areas provide fresh grazing opportunities that are critical for livestock recovery after the winter season, supporting both forage quality and quantity. Conversely, higher elevation areas with limited vegetation cover are less suitable during this period, as snow accumulation and low temperatures restrict pasture accessibility (Legese et al., 2025).

During the summer season, suitability shifts toward mid- and high-elevation grasslands, where cooler temperatures and adequate moisture sustain grass productivity. Summer distribution maps indicate that nomadic herders can exploit a broader range of pastures, allowing rotational grazing practices that prevent overuse of lowland areas. The temporal expansion of suitable zones also highlights the importance of mobility in pastoral systems, ensuring that livestock can access optimal forage conditions throughout the growing season. In contrast, areas experiencing prolonged dry spells or water scarcity, particularly in south-facing slopes and arid lowlands, remain marginally suitable even in summer.

Autumn brings another shift in suitability patterns. As precipitation declines and vegetation starts senescing, lower elevation pastures regain importance due to their milder climatic conditions and remaining forage availability. Herders often begin the seasonal migration toward winter camps during this period, taking advantage of accessible pastures with residual vegetation to sustain livestock prior to winter. The autumn distribution maps, therefore, reflect strategic land use planning by pastoral communities, balancing forage availability, terrain accessibility, and climatic conditions.

Finally, winter suitability is generally restricted to sheltered valleys, riverine corridors, and lowland steppes that offer protection from extreme cold and deep snow accumulation. High-altitude and exposed areas become highly unsuitable due to severe weather, limited forage, and transportation difficulties. Winter distribution maps highlight the critical importance of permanent water sources and snow-free areas for survival of livestock, indicating that pastoralists must plan their seasonal movements carefully to avoid resource bottlenecks.

Overall, the seasonal distribution maps of land suitability underscore the dynamic nature of nomadic pastoralism and the reliance of herders on environmental heterogeneity. They provide valuable insights for understanding the spatial-temporal patterns of livestock grazing and the adaptive strategies employed by pastoral communities. These maps not only illustrate the ecological basis for pastoral mobility but also offer a framework for sustainable land management and policy planning in regions where traditional nomadic practices remain integral to livelihoods.

Conclusion

For the first time, this study has applied a multi-criteria decision analysis (MCDA) approach to systematically evaluate the suitability of land for nomadic pastoralism, integrating both natural and socio-economic factors. In the assessment, the relative importance of each factor was determined using an analytic hierarchy process (AHP), and the spatial layers were subsequently weighted and overlaid to generate a comprehensive suitability map. This methodological framework allows for a nuanced understanding of how multiple environmental and human-related variables jointly influence the potential for sustainable pastoral land use.

The results of the land suitability evaluation indicate significant seasonal variation. During the winter–spring season, 11.26% of the study area was classified as unsuitable, 18.02% as less suitable, 46.37% as moderately suitable, and 24.35% as highly suitable for nomadic pastoralism. In contrast, during the summer–autumn season, areas deemed unsuitable increased to 23.83%, less suitable to 30.66%, while moderately suitable and highly suitable areas accounted for 30.22% and 15.29%, respectively. These patterns highlight the dynamic nature of pasture availability and quality across seasons, reflecting the interplay of factors such as vegetation growth cycles, water resource distribution, and climatic constraints.

Overall, the findings emphasize that seasonal variation is a critical determinant of pastoral land-use strategies. They underscore the necessity for adaptive grazing management practices that align livestock movements with temporally shifting resources. Furthermore, the study highlights the importance of implementing sustainable pasture use policies and monitoring ecological conditions to mitigate potential degradation. By providing spatially explicit insights into land suitability, this research offers a valuable foundation for policy development, landscape planning, and the long-term resilience of nomadic pastoralism under changing environmental and socio-economic conditions. Ultimately, the study contributes to a more informed understanding of how integrated, multi-criteria approaches can support sustainable management of pastoral landscapes in arid and semi-arid regions.

References

1. Энэрэл, Т., & Мандах, Н. (2020). Бэлчээрийн экосистемийн хангамжийн зарим үйлчилгээг үнэлэх нь (Булган аймгийн Рашаант сумын жишээн дээр). *Geographical Issues*, *20*(1), 54-63.
2. Энхжаргал, Д. (2022). *Булган аймгийн малчдын нүүдлийн хэв шинж, нутаг-бэлчээр ашиглалтын газарзүйн онцлог,* МУИС-ийн профессорын эрдмийн өв, Улаанбаатар, х.190
3. Agency of Land Administration and Management, Geodesy and Cartography. (2020). *Statistical information on land use in Mongolia*. Ulaanbaatar, Mongolia.

4. Agency of Land Administration and Management, Geodesy and Cartography. (2022). *Statistical information on land use in Mongolia*. Ulaanbaatar, Mongolia.
5. Akyol, E., Kaya, A., & Alkan, M. (2016). Geotechnical land suitability assessment using spatial multi-criteria decision analysis. *Arabian Journal of Geosciences*, *9*(7), 498.
6. Balew, A., Legese, B., Kunbushu, D., Nega, W., Alebel, W., Kerbesh, A., & Mijanur Rahman, M. (2022). Identification of Suitable Land for Livestock Production Using GIS-Based Multicriteria Decision Analysis and Remote Sensing in the Bale Lowlands, Ethiopia. *International Journal of Ecology*, *2022*(1), 9585552.
7. Dorjsuren, B., Batsaikhan, N., Yan, D., Yadamjav, O., Chonokhuu, S., Enkhbold, A., ... & Abiyu, A. (2021). Study on relationship of land cover changes and ecohydrological processes of the Tuul River Basin. *Sustainability*, *13*(3), 1153.
8. Goepel, K. D. (2018). Implementation of an online software tool for the analytic hierarchy process (AHP-OS). *International journal of the analytic hierarchy process*, *10*(3).
9. Holben, B. N. (1986). Characteristics of maximum-value composite images from temporal AVHRR data. *International journal of remote sensing*, *7*(11), 1417-1434.
10. Jargalsaikhan, G., & Gombosuren, U. (2021). Effect of rangeland production and quality for livestock body weight. *Mongolian Journal of Agricultural Sciences*, *34*(3), 39-48.
11. Legese, B., Kalura, P., Degife, A., Godana, G., & Chamara, J. (2025). Integrating GIS and Multi-Criteria Analysis for Sustainable Livestock Grazing: A Holistic Assessment of Biophysical and Socio-Economic Determinants in Semi-Arid Dawa Watershed of Ethiopia. *Land Degradation & Development*.
12. Li, Q., Wang, J., Xie, H., Ochir, A., & Davaasuren, D. (2022). Applicability of grassland production estimation using remote sensing for the Mongolian Plateau by comparing typical regions in China and Mongolia. *Sustainability*, *14*(5), 3122.
13. Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. *International journal of geographical information science*, *20*(7), 703-726.
14. Mungunchimeg, N., Ganbold, B., Sonomdagva, C., & Jambajamts, L. (2024). Changes in the biomass of pasture plants and some impacts in Mongolia. *Geographical Issues*, *24*(02), 16-31.
15. Nyamaa, T., Sainbuyan, B., Narantsatsral, T., Lan, A., Urtnasan, M., Baoyin, T., ... & Munkh-Erdene, J. (2024). The influence of socio-economic factors on net primary products of Mongolia during 2000-2021. *Geographical Issues*, *24*(01), 63-76.
16. Qiu, F., Chastain, B., Zhou, Y., Zhang, C., & Sridharan, H. (2014). Modeling land suitability/capability using fuzzy evaluation. *GeoJournal*, *79*(2), 167-182.
17. Rao, M. P., Davi, N. K., D D'Arrigo, R., Skees, J., Nachin, B., Leland, C., ... & Byambasuren, O. (2015). Dzuds, droughts, and livestock mortality in Mongolia. *Environmental Research Letters*, *10*(7), 074012.
18. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, *15*(3), 234-281.
19. Sheridan, P., Smith, S., Brown, A., & Vosper, S. (2010). A simple height-based correction for temperature downscaling in complex terrain. *Meteorological Applications*, *17*(3), 329-339.
20. Yan, N., Zhu, W., Wu, B., Tuvdendorj, B., Chang, S., Mishigdorj, O., & Zhang, X. (2023). Assessment of the grassland carrying capacity for winter-spring period in Mongolia. *Ecological Indicators*, *146*, 109868.
21. Zhao, Q., & Qu, Y. (2024). The retrieval of ground ndvi (normalized difference vegetation index) data consistent with remote-sensing observations. *Remote Sensing*, *16*(7), 1212.