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GEOINFORMATION MAPPING OF PASTURE LANDS IN THE SOUTHERN REGIONS OF KAZAKHSTAN BASED ON EARTH REMOTE SENSING DATA

Annotation. This article presents the results of geoinformation mapping of pasture lands in the southern regions of Kazakhstan based on Earth remote sensing data, GIS analysis and field geobotanical surveys. The study objects were pasture areas of Almaty, Zhambyl, Zhetysu, Kyzylorda and Turkestan regions, which differ in contrasting natural and climatic conditions, heterogeneous soil and vegetation cover, different degrees of aridity and anthropogenic pressure. The relevance of the research is determined by the need to create an objective digital basis for assessing the state of pastures, clarifying their spatial distribution and substantiating permissible grazing load at the district level. The source materials included regional and district administrative boundaries, medium-resolution satellite imagery, digital land-use layers, results of visual expert interpretation and field data on species composition, projective cover, grass height, productivity and forage value of pasture vegetation. The methodology included the development of a spatial database, delineation of pasture lands, exclusion of non-pasture objects, calculation of vegetation biophysical parameters and comparison of satellite information with field survey data. Differences in natural zones, seasonal dynamics of grass cover and spectral homogeneity of plant formations were also considered when selecting test polygons. GIS processing produced digital pasture maps for five regions and assessed LAI, FAPAR and FCOVER, which characterize leaf biomass development, photosynthetic activity and the fraction of the surface covered by green vegetation. The results revealed pronounced regional differentiation of pasture condition: more favorable values of biophysical parameters were recorded for Almaty and Zhetysu regions, whereas pastures in Turkestan, Zhambyl and Kyzylorda regions were characterized by more limited bioproductive potential. Field geobotanical surveys made it possible to refine vegetation formation types, verify interpretation results and improve the reliability of thematic mapping. The obtained materials can be used for rational pasture use, spatial planning of grazing load, development of district-level standards and prevention of degradation of pasture ecosystems in southern Kazakhstan.

Keywords: pasture lands; Earth remote sensing; GIS; biophysical parameters; geobotanical survey; grazing load; southern Kazakhstan; LAI; FAPAR; FCOVER; permissible grazing load.

Introduction

Pasture lands are a basic spatial resource for livestock production in arid and semi-arid regions of Kazakhstan. Their condition depends on the combined influence of climatic factors, soil and vegetation conditions, seasonal grassland dynamics and the actual intensity of use. According to state land accounting data, a considerable part of the country’s pastures is in unsatisfactory condition, which reduces forage availability and increases the risk of land degradation [1-3].

Existing national standards for maximum permissible pasture load are generalized and do not always reflect intra-territorial differences in vegetation productivity, soil salinity, moisture availability and accessibility of pasture plots. In the context of changes in pasture legislation, this issue has direct applied significance because the assessment of actual and permissible load is used for land-use regulation [4-8].

Modern methods of Earth remote sensing provide spatially continuous indicators of vegetation condition, including leaf surface, fraction of absorbed photosynthetically active radiation and fractional green vegetation cover. In combination with GIS analysis and field geobotanical surveys, these data make it possible to move from local descriptions of grass cover to district-differentiated grazing-load standards [9-15].

The aim of the study is to develop a scientifically substantiated approach to the assessment of pasture lands in the southern regions of Kazakhstan and to calculate permissible grazing load at the district level through the integration of remote sensing, GIS and field geobotanical observations.

Materials and methods

Study area

The study objects were pasture lands of Almaty, Zhambyl, Zhetysu, Kyzylorda and Turkestan regions of the Republic of Kazakhstan. These territories belong mainly to arid and semi-arid natural zones, where pasture productivity varies substantially depending on elevation, soil cover, salinity, moisture conditions and anthropogenic pressure. All regions are characterized by a high spatial heterogeneity of pasture vegetation, which requires analysis at the district scale [1-8].

Source data and geodatabase

The source information base included administrative boundaries of regions and districts, medium-resolution satellite images, materials of visual expert interpretation, thematic pasture-land layers and field survey results. Spatial data were organized in a geodatabase, where each object was assigned geometric and attribute characteristics: administrative affiliation, area, land-use type, membership in a test polygon and ground-verification results.

Both direct and indirect interpretation features were used to identify pastures. Cropland was recognized by regular field geometry and a pronounced mosaic pattern of agricultural use; fallow land by less regular contours and heterogeneous spectral structure; hayfields by denser seasonal grass cover; and pastures by their position relative to settlements, livestock trails, watering points and trampling traces. Examples of interpretation features are presented in Figure 1.

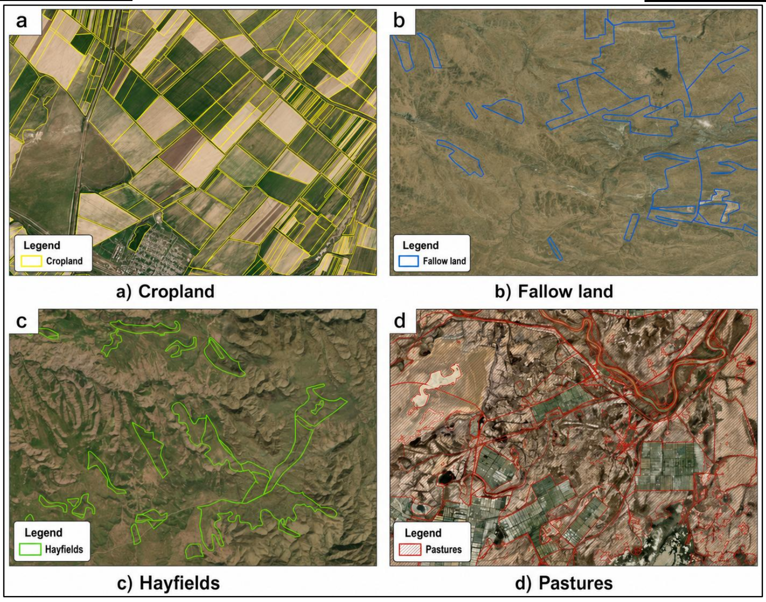

Figure 1 - Interpretation features of agricultural lands based on remote sensing data: a) cropland; b) fallow land; c) hayfield; d) pasture

Figure 2 presents an example of the attribute structure of the geodatabase. A unified object table makes it possible to calculate areas, link polygon data with biophysical parameters and compile district-level summaries for grazing-load regulation.

Table

Zhetysu_region

ObjectName	OblName	SHAPE_Length	SHAPE_Area	area
Aksu district	Zhetysu Region	179,689836	1,067551	926768,261401498
Alakol district	Zhetysu Region	351,630238	1,763859	1524315,77482008
Taldykorgan city	Zhetysu Region	116,929575	0,259402	227753,374518348
Karatal district	Zhetysu Region	125,361618	2,420252	2093089,54183008
Kerbulak district	Zhetysu Region	181,942278	0,802653	712620,245404545
Koksu district	Zhetysu Region	72,644631	0,724577	637549,833080487
Panfilov district	Zhetysu Region	114,597042	0,599159	533949,37193362
Sarkand district	Zhetysu Region	177,63014	1,976983	1691083,15892226

Figure 2 - Example of the attribute table of the pasture-land layer in the geodatabase

Remote sensing processing and biophysical parameters

The condition of pasture vegetation was assessed from remote sensing data during the period of maximum grassland growth. The main biophysical parameters were LAI (Figure 3), FAPAR (Figure 4) and FCOVER (Figure 5). LAI characterizes leaf surface area per unit of ground surface; FAPAR reflects the fraction of photosynthetically active radiation absorbed by green vegetation; and FCOVER describes the fraction of the surface covered by green vegetation [10]. These indicators are used to assess biomass, seasonal grassland development and spatial heterogeneity of pastures.

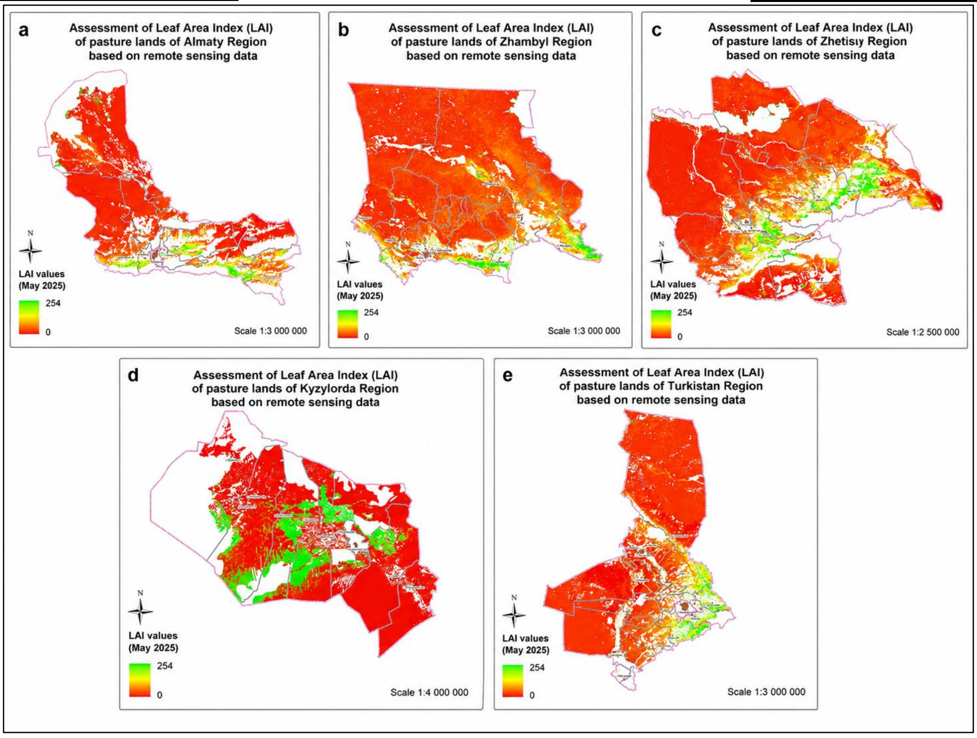

Figure 3 - Assessment of Leaf Area Index (LAI) of pasture lands in the southern regions of Kazakhstan based on Earth remote sensing data for May 2025: a – Almaty Region; b – Zhambyl Region; c – Zhetysu Region; d – Kyzylorda Region; e – Turkestan Region

The Leaf Area Index (LAI) was used for quantitative assessment of leaf biomass development in pasture vegetation. This indicator expresses the ratio of total leaf surface area to a unit of ground surface and is one of the key biophysical parameters for analyzing grassland productivity. In this study, LAI was calculated using Earth remote sensing data for May 2025, which corresponds to the period of active development of pasture vegetation. Multispectral data were used to characterize the spectral response of vegetation in the visible, near-infrared and short-wave infrared ranges. LAI estimation is based on the relationship between vegetation reflectance and leaf-mass density: areas with more developed grass cover generate higher values, whereas sparse, dry or degraded pastures show low values [11, 12].

The spatial distribution of LAI demonstrates pronounced regional heterogeneity of pasture lands. The highest values occur in Almaty and Zhetysu regions, where foothill and mountain conditions, better moisture supply and relatively well-developed grass cover promote greater leaf surface. Mean LAI values were approximately 6.57 for Almaty Region and 6.68 for Zhetysu Region. These territories can be interpreted as zones with comparatively high potential for green biomass formation.

In Zhambyl Region the mean LAI value was approximately 3.91, indicating more limited leaf-mass development than in Almaty and Zhetysu regions. Spatially higher values are confined to southern and foothill areas, whereas flat arid territories are characterized by low values. In Kyzylorda Region the mean LAI was about 4.02, but the distribution is heterogeneous: a large part of pastures has low values, while locally increased values are associated with more favorable moisture conditions. In Turkestan Region the mean LAI was about 3.41, reflecting the strong influence of aridity, seasonal moisture deficit and high anthropogenic pressure. Therefore, the LAI map makes it possible to identify areas with different levels of leaf biomass development and to use this parameter as a basis for subsequent assessment of pasture forage potential [13-15].

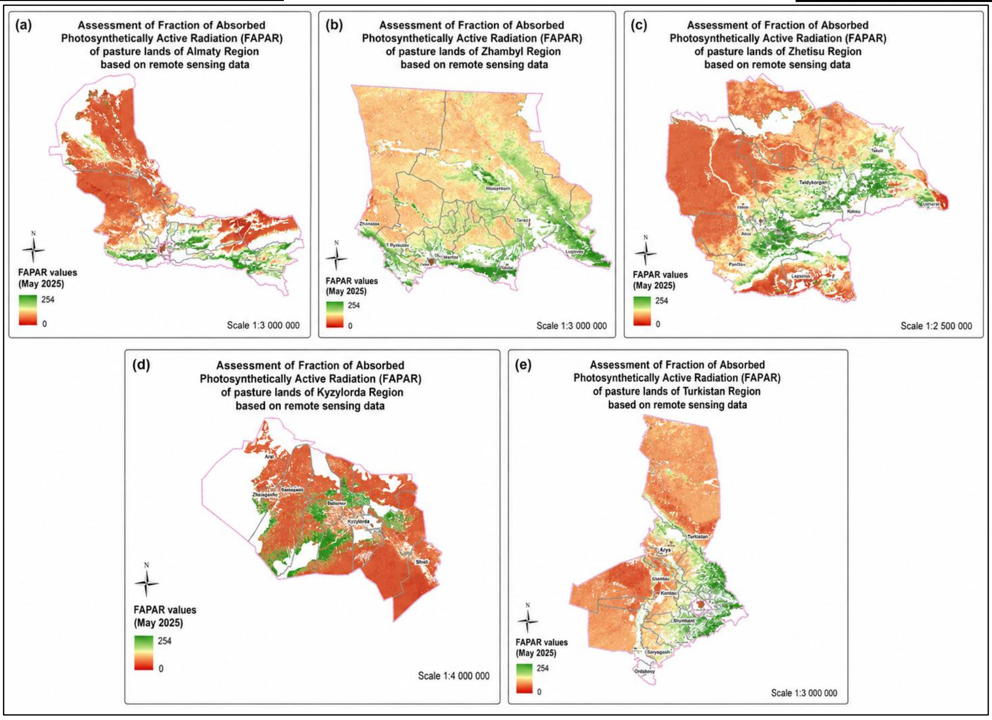

Figure 4 - Assessment of Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) of pasture lands in the southern regions of Kazakhstan based on Earth remote sensing data for May 2025: a – Almaty Region; b – Zhambyl Region; c – Zhetysu Region; d – Kyzylorda Region; e – Turkestan Region

FAPAR reflects the fraction of photosynthetically active radiation absorbed by green vegetation. Unlike LAI, which characterizes the structural parameter of leaf surface, FAPAR describes the functional activity of vegetation cover, that is, the ability of pasture vegetation to use solar energy in photosynthesis. FAPAR was calculated from remote sensing data for May 2025 based on vegetation spectral characteristics. High values correspond to areas with active photosynthesis, sufficient green biomass and favorable grassland condition. Low values indicate weak vegetation activity, sparse cover, drought stress or predominance of exposed soil.

The FAPAR map clearly shows regional differences in the functional state of pastures. In Almaty Region, elevated values are concentrated mainly in the southern and south-eastern parts, where foothill and mountain pastures have better moisture conditions. Northern and flat areas are characterized by lower values, reflecting aridization and limited grassland development. In Zhambyl Region, FAPAR values vary spatially from low and medium levels in flat dry areas to higher levels in the southern and foothill parts. The mean FAPAR for Zhambyl Region was about 21.43, indicating moderately limited photosynthetic activity of pasture vegetation.

For Zhetysu Region, the map shows considerable spatial contrast: high FAPAR values are associated with central, southern and eastern areas, where relief and moisture conditions support active vegetation development. In Kyzylorda Region, the mean FAPAR was about 52.49, although this value should be interpreted carefully because high values are not spatially continuous but occur locally on more active vegetation sites. At the same time, the overall closure of green cover in this region remains low, as confirmed by FCOVER. In Turkestan Region, the mean FAPAR was about 18.13. Higher values are concentrated in the southern and foothill parts, whereas northern arid pastures show lower photosynthetic activity. Thus, FAPAR makes it possible to assess not only the presence of vegetation but also its physiological activity during a specific vegetation period.

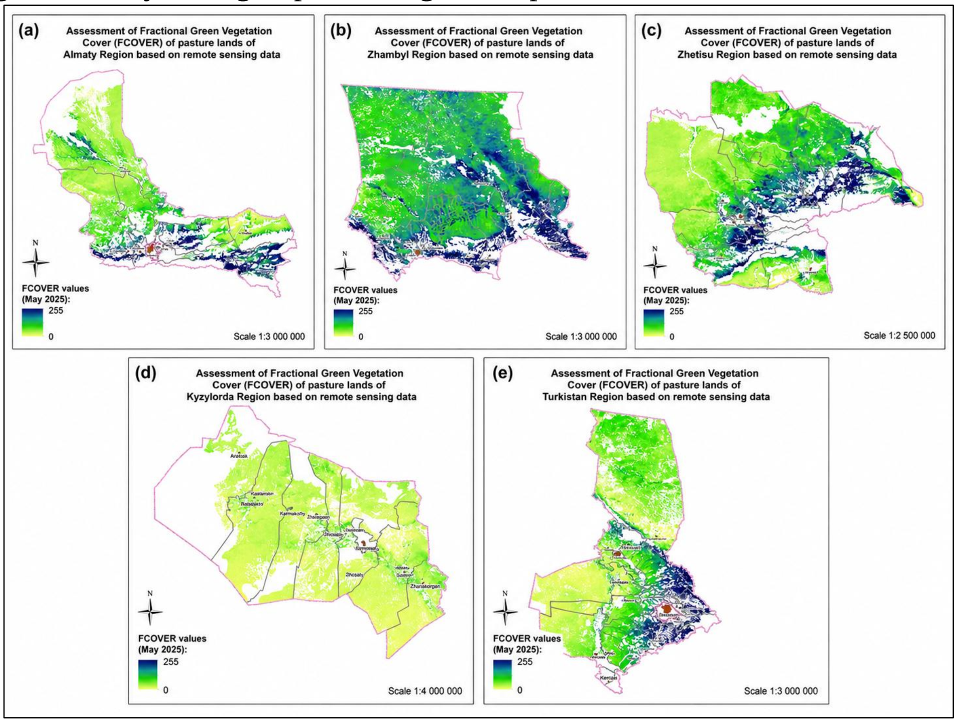

Figure 5 - Assessment of Fractional Green Vegetation Cover (FCOVER) of pasture lands in the southern regions of Kazakhstan based on Earth remote sensing data for May 2025: a – Almaty Region; b – Zhambyl Region; c – Zhetysu Region; d – Kyzylorda Region; e – Turkestan Region

FCOVER was used to estimate the fraction of the surface covered by green vegetation. Unlike LAI and FAPAR, this parameter directly characterizes the closure of green cover and the degree to which the surface is covered by plant mass. FCOVER is especially important for the analysis of pasture lands in arid and semi-arid territories because sparse grass cover is directly related to the risk of degradation, trampling, soil deflation and reduced forage capacity. FCOVER was calculated from Earth remote sensing data for May 2025. High values correspond to areas with dense green cover, whereas low values indicate weak vegetation development, exposed soil, saline sites or low-productivity pastures.

The spatial distribution of FCOVER shows that the most favorable conditions for formation of green cover are typical of Zhetysu and Almaty regions. The mean FCOVER for Zhetysu Region was about 46.31, the highest value among the studied regions. This indicates greater closure of pasture cover and relatively high potential for maintaining grassland stability. In Almaty Region, the mean FCOVER was about 35.95. On the map, higher values are concentrated in the southern and foothill territories, whereas northern and flat areas have more sparse cover.

In Zhambyl Region, the mean FCOVER was about 32.98. Spatially higher values are observed in the southern and south-eastern parts of the region, where pasture vegetation develops better due to relief and moisture conditions. In Kyzylorda Region, the mean FCOVER was about 14.94, which indicates the most sparse green cover among the five regions. This is associated with high aridity, soil salinity and limited development of herbaceous vegetation. In Turkestan Region, the mean FCOVER was about 25.43. The densest green cover is formed in the southern and foothill zone, whereas northern and western pastures show lower values. Taken together, FCOVER refines the actual closure of pasture cover and is an important parameter for assessing degradation risk and permissible grazing load.

Field geobotanical surveys and cross-checking

Figure 6 presents a map of relief, hydrographic network and field points used for the geobotanical survey of pasture lands in the southern regions of Kazakhstan. The cartographic base covers Almaty, Zhambyl, Zhetysu, Kyzylorda and Turkestan regions, which are characterized by substantial natural heterogeneity. Within the study area, elevations range from lowland plains in Kyzylorda Region to high-mountain territories of south-eastern Kazakhstan. This altitudinal differentiation directly affects types of pasture vegetation, duration of the vegetation period, moisture availability, grassland productivity and permissible grazing load.

Test polygons for field verification and geobotanical description were selected considering the results of preliminary remote classification, spectral homogeneity of plant formations, relief conditions and territorial accessibility. Particular attention was paid to ensuring that control points covered different natural-landscape conditions: flat arid pastures, foothill sites, mountain pastures, areas near the hydrographic network, sandy zones, and sites located near settlements and livestock-driving routes. This approach improved the representativeness of field data and reduced the risk of one-sided pasture assessment based only on the most accessible areas.

At least 30 test polygons were planned for each administrative district. At each polygon, geographic coordinates, administrative affiliation, landscape-geographic position, elevation conditions, soil type, dominant plant species, total projective cover, average grass height, and productivity of fresh and dry pasture mass were recorded. Additional degradation signs were noted, including sparse vegetation, exposed soil, trampling traces, and proximity to watering points, livestock trails and settlements.

The map shows that field points are distributed unevenly but in accordance with the spatial logic of pasture use and the natural differentiation of the territory. A higher density of points is observed in areas of active agricultural use, in foothill zones and along transport-accessible territories. In Kyzylorda Region, points mainly cover arid and semi-desert pastures, where sandy massifs, saline soils and a limited hydrographic network play an important role. In Turkestan and Zhambyl regions, a large part of the points is associated with foothill and flat-foothill pastures, where high seasonal variability of grass cover is observed. In Almaty and Zhetysu regions, field points cover a broad elevation range from flat pastures to mountain and foothill sites, allowing the influence of relief and moisture to be considered in vegetation assessment.

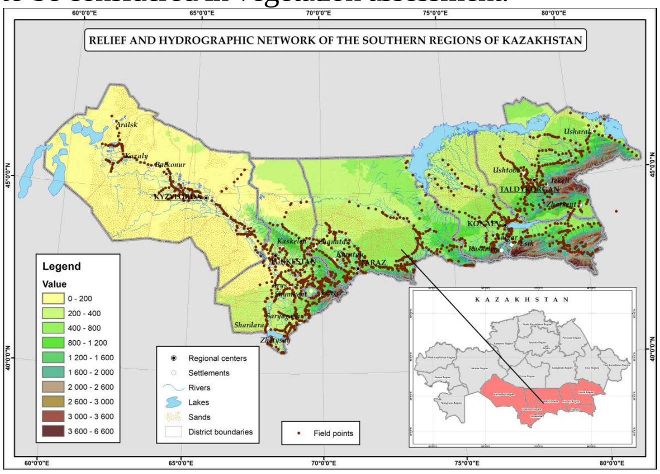

Figure 6 - Relief, hydrographic network and spatial distribution of field points in the southern regions of Kazakhstan

The presented map has not only illustrative but also methodological value. It shows the spatial relationship between relief, the hydrographic network, administrative boundaries and the actual distribution of field surveys. This is important for the subsequent verification of remote sensing data because LAI, FAPAR and FCOVER spectral indicators must be interpreted with regard to the landscape position of pastures. For example, low biophysical-parameter values in desert and semi-desert areas may reflect natural sparseness of vegetation, whereas similar values in foothill pastures may indicate degradation or excessive grazing load.

Thus, the map of relief, hydrographic network and field points provides the spatial basis for comparing satellite data with field geobotanical surveys. It enables correct interpretation of pasture formations, assessment of grassland productivity and subsequent calculation of permissible grazing load at the district scale.

Figure 7 shows the combination of the cartographic position of a test plot with the actual condition of grass cover. This procedure is necessary for cross-checking remote sensing data because satellite indicators reflect an integral spectral signal, whereas field surveys refine species composition, forage value and degradation features.

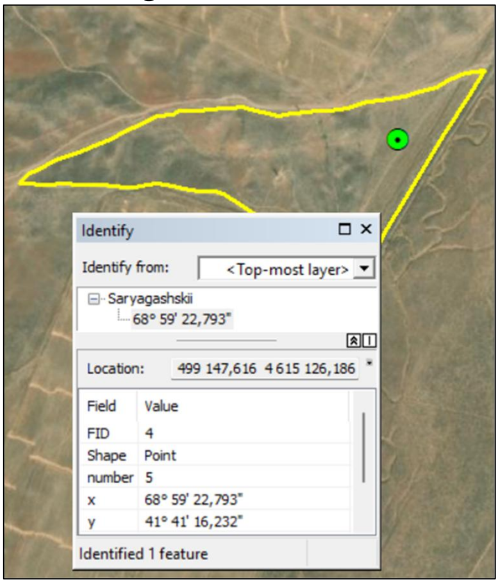

Figure 7 - Example of a test polygon and the actual grassland condition at a geobotanical survey site

Calculation of permissible grazing load

Permissible grazing load was calculated on the basis of dry pasture-mass productivity, the utilization coefficient and the annual dry-matter requirement of one conditional livestock unit. Methodologically, the calculation was performed after identifying dominant types of pasture vegetation and comparing biophysical parameters with ground measurements of productivity:

$$D = (Y \times K) / P$$

where D is permissible load; Y is the mean yield of dry pasture mass, c/ha; K is the utilization coefficient of pasture mass; and P is the annual dry-matter requirement of one conditional livestock unit, c. In the practical calculation, the utilization coefficient was taken within the range of 0.5-0.6, which reflects the inadmissibility of complete removal of aboveground biomass and the need to preserve the regenerative potential of the pasture.

Results and discussion

Digital mapping of pasture lands

As a result of visual expert interpretation of satellite data and subsequent GIS processing, digital maps of pasture lands were prepared for five southern regions of

Kazakhstan: Almaty, Zhambyl, Zhetysu, Kyzylorda and Turkestan regions. The main task of this stage was not only to determine the total pasture area but also to create a spatially correct pasture mask suitable for further calculation of biophysical parameters, geobotanical interpretation and assessment of permissible grazing load.

Digitization was performed by sequentially excluding objects that do not belong to pasture lands from the initial spatial mask. Croplands, hayfields, fallow lands, settlements, road networks, water bodies, industrial and infrastructure areas, and sites with signs of stable non-pasture use were excluded from the analysis. This approach reduced the probability of mixing pastures with other land categories, especially in arid and semi-arid conditions where the spectral characteristics of dry pastures, fallow lands and low-productivity hayfields may be similar.

During visual expert interpretation, contour shape and size, image texture, seasonal variability of vegetation cover, and the spatial position of plots relative to settlements, watering points, roads and livestock trails were considered. Pasture plots, unlike croplands, generally do not have a regular geometric structure and are characterized by a more heterogeneous spectral pattern. Therefore, their delineation required the combined use of satellite information, cartographic data and expert interpretation of spatial context (table 1).

Table 1 - Area of digitized pasture lands by study region

Region	Area of digitized pastures, ha
Almaty Region	6 323 376.9
Zhambyl Region	8 347 129.5
Zhetysu Region	8 336 535.2
Kyzylorda Region	15 143 297.1
Turkestan Region	9 119 936.5

The largest pasture area was delineated in Kyzylorda Region, which is associated with the dominance of extensive arid territories and a low share of intensively cultivated land. Turkestan, Zhambyl and Zhetysu regions also contain considerable pasture resources, but their forage potential differs because of differences in moisture conditions, soil cover and anthropogenic pressure (Figure 8).

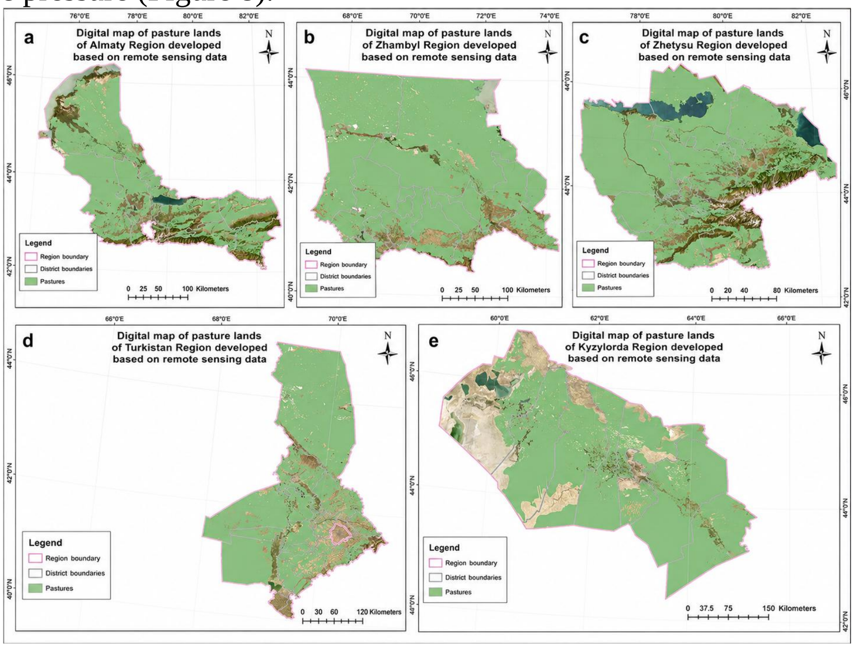

Figure 8 - Digital maps of pasture lands in the southern regions of Kazakhstan developed from remote sensing data

Regional differentiation of biophysical parameters

Comparative analysis of LAI, FAPAR and FCOVER revealed regional differences in the condition of pasture vegetation. The highest mean LAI values were recorded in Zhetysu and Almaty regions, indicating better development of leaf biomass. Lower LAI values in Turkestan and Zhambyl regions reflect a limited potential for grassland formation under drought and uneven moisture conditions (table 2).

Table 2 - Mean values of pasture vegetation biophysical parameters by study region

Region	LAI	FAPAR	FCOVER
Almaty Region	6.57	n/a	35.95
Zhambyl Region	3.91	21.43	32.98
Zhetysu Region	6.68	n/a	46.31
Kyzylorda Region	4.02	52.49	14.94
Turkestan Region	3.41	18.13	25.43

For FCOVER, the maximum values were recorded in Zhetysu and Almaty regions, confirming a higher closure of green cover. Kyzylorda Region is characterized by high FAPAR combined with low FCOVER, which indicates spatial heterogeneity of vegetation cover: photosynthetically active sites occur, but their area and closure are limited. Therefore, no single biophysical parameter should be used in isolation; a correct pasture assessment requires joint analysis of LAI, FAPAR, FCOVER and ground productivity.

Geobotanical interpretation of pasture productivity

Field geobotanical surveys showed substantial differences in the condition of pasture vegetation among the studied regions. The main indicators used to characterize grass cover were total projective cover, vegetation height, species composition, fresh and dry mass productivity and signs of pasture-cover disturbance. These parameters are directly relevant to the assessment of pasture forage potential because satellite biophysical indicators represent the integral state of vegetation cover, whereas field data clarify the actual structure and economic value of grassland (Figure 9).

Figure 9 - Field geobotanical work: recording and description of grass cover, work at a test site, and fixation of spatial position and pasture condition

In Almaty Region, total projective cover of pasture vegetation ranged from 60 to 100%, indicating considerable heterogeneity of pasture conditions. The highest cover values were typical of foothill and mountain sites with better moisture availability, more developed grass cover and favorable soil conditions. The average pasture productivity was about 10-15 c/ha; however, substantial differences were observed within the region between flat arid sites and more productive foothill pastures. Therefore, Almaty Region can be considered a region with relatively high but spatially contrasting pasture potential.

In Zhambyl Region, grassland productivity ranged from 0.5 to 13.7 c/ha, with an average level of about 5-6 c/ha. This range shows that a considerable part of pastures has limited forage capacity. Low productivity values are associated with climatic aridity, uneven seasonal moisture, sparse grass cover and local anthropogenic impact. At the same time, individual sites, especially in foothill and better-moistened zones, form higher biomass. Consequently, the use of uniform averaged grazing-load standards for Zhambyl Region is insufficiently correct because it does not reflect intra-territorial productivity differences.

In Zhetysu Region, mean pasture productivity was approximately 6-7 c/ha. This region combines flat, foothill and mountain pastures, creating pronounced landscape differentiation of vegetation cover. More productive pastures are associated with better-moistened sites and more stable grass cover, whereas productivity decreases in dry flat areas. Field data confirm that the high spatial variability of relief and soil-vegetation conditions must be considered when interpreting satellite indices and calculating permissible load.

In Turkestan Region, the mean productivity of pasture vegetation was approximately 3-4 c/ha. Low and medium productivity values are caused by high seasonal drought, a short period of active grassland development and considerable grazing pressure near settlements and watering points. However, southern and foothill parts of the region have more favorable conditions for grassland development than flat arid territories. Therefore, pasture assessment in Turkestan Region must consider not only total land area but also seasonal accessibility, degree of use and spatial proximity to zones of livestock concentration.

In Kyzylorda Region, mean pasture productivity was about 2.0-2.5 c/ha, one of the lowest values among the studied regions. This is associated with the dominance of desert and semi-desert landscapes, high aridity, widespread saline soils, sparse vegetation and a limited hydrographic network. Even with a large area of pasture lands, the actual forage capacity of these territories remains limited. For this region, it is especially important to consider not only biomass productivity but also the resistance of the soil-vegetation cover to the mechanical impact of grazing.

The identified differences are of fundamental importance for grazing-load regulation. For pasture plots of the same size, permissible load cannot be identical where productivity, projective cover and aridity differ. Sites with low productivity, weak grass cover and a high share of exposed soil should have a lower permissible load because excessive biomass removal on such areas rapidly leads to vegetation degradation, trampling and intensification of erosion processes. Conversely, sites with high projective cover, stable grassland and sufficient biomass may sustain a higher but strictly regulated load.

Thus, the use of pasture area alone without considering biomass, species composition, projective cover and typological structure of vegetation leads to overestimation of calculated pasture capacity. A correct assessment of permissible load should be based on joint analysis of field geobotanical data, satellite biophysical parameters and natural-landscape conditions. This approach enables a transition from administratively averaged standards to a spatially differentiated pasture-management system in which each district and pasture type is considered with regard to its actual forage potential and ecological stability.

Permissible grazing load and GIS-based management

The calculation of permissible grazing load was carried out considering regional and district heterogeneity of pastures. The main scientific result is not limited to the production of pasture maps; it also consists in forming a spatial basis for management decisions: where the current load is acceptable, where livestock numbers need to be reduced, where pasture rotation is required and where restoration measures are appropriate.

The GIS approach makes it possible to link calculated standards to specific administrative districts and individual pasture massifs. This is especially important for southern Kazakhstan, where gradients of aridity, elevation and soil salinity create sharp spatial differences in productivity. District-differentiated standards reduce the risk of both overloading degraded pastures and underusing more productive sites.

Methodological detail of pasture mask preparation

Preparation of the pasture mask was considered as an independent stage because the accuracy of all subsequent calculations depends on its completeness. In the GIS environment, the initial territory was sequentially cleaned of objects that do not belong to pastures: croplands, hayfields, fallow lands, settlements, road networks, industrial sites, water bodies and areas with permanent surface transformation. This procedure prevented mechanical mixing of pasture vegetation with other land categories and reduced the risk of overestimating forage capacity.

Visual expert interpretation was used not as a replacement for automated classification but as a corrective mechanism for complex arid territories. In southern Kazakhstan, the spectral similarity of dry pastures, fallow lands and low-productivity hayfields leads to automated-classification errors, especially during periods of low phytomass. Therefore, the study considered contour shape, image texture, seasonal recurrence of the spectral signal, location relative to settlements and watering points, and traces of livestock trails.

To increase comparability, all vector layers were brought to a single coordinate system and a unified attribute structure. The attribute component included polygon identifier, administrative affiliation, area, interpretation source, land type, correction attribute and additional fields required for linkage with raster indicators. Such a geodatabase structure enables updating of materials when new images and repeated field surveys become available.

Topological checking of polygon layers was of particular importance. Self-intersections, duplicated contours, boundary gaps and small artifact polygons arising from manual vectorization and subsequent layer merging were eliminated. After topological cleaning, areas were calculated by region and district, which provided a consistent spatial basis for regional analysis.

Interpretation of biophysical parameters under arid pasture conditions

LAI, FAPAR and FCOVER were interpreted with regard to the natural zonality of pastures. In arid and semi-arid conditions, low values of these parameters do not always indicate degradation: they may reflect naturally sparse vegetation types, a short period of active vegetation or dominance of semi-shrub communities. Therefore, the assessment was not based on a single absolute threshold but on comparison of indicators with pasture type, regional climatic conditions and geobotanical descriptions.

LAI was used as an indicator of leaf-surface volume and potential biomass. Increased LAI values are typical of areas with developed grass cover and better moisture availability, whereas low values reflect weak leaf-mass development or the completion of a phenological phase. FAPAR characterizes the fraction of absorbed photosynthetically active radiation and makes it possible to assess the functional activity of vegetation cover, including sites where projective cover is low but plants are in an active photosynthetic phase.

FCOVER reflects the fraction of the surface covered by green vegetation and is therefore especially important for assessing the sparseness of pasture cover. In Kyzylorda Region, the combination of relatively high FAPAR with low FCOVER indicates heterogeneity of vegetation cover: some sites retain photosynthetic activity, but the spatial closure of grass cover remains limited. For grazing-load regulation, this result has practical significance because low cover increases the risk of trampling and soil deflation.

The integrated interpretation of the three parameters made it possible to separate territories with high biomass potential, sites with limited productivity and pastures with high spatial heterogeneity. This is important for district-level regulation because the same mean yield may result from different combinations of cover density, photosynthetic activity and grassland structure (Table 3).

Table 3 - Functional interpretation of biophysical indicators for pasture assessment

Indicator	**Biophysical meaning**	**Interpretation for pastures**
LAI	Leaf surface area per unit of ground area	Characterizes potential green biomass volume and the phenological phase of grassland development
FAPAR	Fraction of absorbed photosynthetically active radiation	Shows functional activity of vegetation cover and photosynthesis intensity
FCOVER	Fraction of the surface covered by green vegetation	Reflects grassland closure, cover sparseness and risk of soil exposure

Regional geobotanical characteristics and productivity differences

Geobotanical surveys confirmed considerable intra-territorial heterogeneity of pasture lands. In Almaty Region, projective cover during the active growth period ranged from 60 to 100%, while productivity varied from 2.0-2.5 c/ha on saline and degraded sites to 70-72 c/ha on the most productive pastures. This difference is explained by the combination of foothill conditions, local moisture, soil heterogeneity and different degrees of economic pressure.

In Zhambyl Region, mean projective cover was 70-100%, but productivity varied within a narrower and predominantly low range of 0.5 to 13.7 c/ha. This indicates limited forage potential in a substantial part of surveyed pastures and the need for cautious use of averaged standards. On such territories, excessive load may quickly reduce the share of edible species and intensify degradation signs.

In Zhetysu Region, projective cover also ranged from 60 to 100%, and productivity varied from 2.0-2.5 to 12.5 c/ha. Despite high biophysical-parameter values in the regional comparison, field information shows that productivity depends on local soil and climatic conditions and cannot be evaluated only by a regional mean value.

Turkestan Region was characterized by projective cover of 60-100% and productivity from 1.7-2.0 to 7.5-8.7 c/ha. Under relatively mild winter conditions and early onset of spring vegetation, the role of seasonal drought is high and limits the duration of the productive period. Therefore, monitoring should consider specific phenological windows rather than calendar months only.

In Kyzylorda Region, projective cover was 50-90%, with an average of 70-75%, and productivity ranged from 1.2-1.5 to 5.0-6.2 c/ha. Low values are associated with strong aridity, widespread saline soils and sparse vegetation cover. For this region, the most critical issue is not only calculation of forage mass but also accounting for the resistance of the soil surface to additional mechanical impact from grazing (Table 4).

Table 4 - Regional geobotanical indicators used for grazing-load assessment

Region	Projective cover	Grassland productivity, c/ha	Interpretation
Almaty Region	60-100%, mean 80-85%	from 2.0-2.5 to 70-72	The most contrasting conditions: from degraded and saline sites to highly productive pastures
Zhambyl Region	70-100%	from 0.5 to 13.7	Limited forage potential in a substantial part of pastures
Zhetysu Region	60-100%	from 2.0-2.5 to 12.5	High dependence of productivity on local soil and climatic conditions
Turkestan Region	60-100%	from 1.7-2.0 to 7.5-8.7	Early grassland development with a strong role of seasonal drought
Kyzylorda Region	50-90%, mean 70-75%	from 1.2-1.5 to 5.0-6.2	Sparse cover and high influence of salinity and aridity

Linkage between field biomass and remote sensing data

The linkage between field measurements and remote sensing data was formed through control polygons where geographic coordinates, species composition, grass height, projective cover and productivity were recorded simultaneously. Biophysical-parameter values were extracted for each polygon from the corresponding raster layers. This made it possible to form a training and validation basis for assessing the correspondence between satellite signal and actual pasture condition.

Field data should not be regarded only as a means of verifying a completed map. They perform a calibration function: they clarify the meaning of spectral differences and allow naturally low-productivity pastures to be distinguished from anthropogenically degraded ones. For example, low FCOVER on saltwort or wormwood pastures may be a natural property of the community, whereas a similar value on sites that previously had denser grass cover may indicate degradation.

A regression approach was used to convert satellite indicators into productivity. The dependent variable was dry-mass yield determined from mowing plots, while the independent variables were LAI, FAPAR, FCOVER and additional features characterizing pasture type. This approach is methodologically preferable to simple interpolation of field measurements because it accounts for the spatial continuity of satellite observations and extends survey results to the entire district territory.

In practical application, regression relationships should be developed separately for major natural-vegetation groups or corrected using a typological coefficient. I disagree with the use of a universal model for all regions: a single model would mix wormwood, ephemeral, grass and saltwort communities, resulting in distortion of productivity and, consequently, permissible load. The correct approach requires stratification by pasture types and natural zones.

Spatial logic of permissible grazing-load calculation

Permissible grazing load was calculated not as a single tabular value but as a spatially distributed procedure. At the first stage, dry-mass productivity was determined for each polygon or cell of the pasture mask. At the second stage, the utilization coefficient was applied, reflecting the share of forage mass that can actually be used by animals without destroying the vegetation cover. At the third stage, the calculation was related to the annual dry-matter requirement of one conditional livestock unit.

The use of a utilization coefficient of 0.5-0.6 is an important limiting factor. If the entire biomass is accepted as available forage, the calculated load will be overestimated because part of the plants is not eaten, and another part must remain for grassland recovery, soil protection and seed renewal. In districts with low projective cover, it is appropriate to use the lower coefficient boundary because the ecological risk of biomass removal is higher.

The resulting indicator can be presented in two interrelated forms: as the permissible number of conditional livestock units per unit area or as the required pasture area per one conditional livestock unit. For district-level management tasks, the second form is often clearer because it shows how many hectares are required for sustainable maintenance of one conditional livestock unit at a given productivity and use duration.

Spatial mapping of permissible load allows identification of zones of deficient pasture capacity, territories of potential overload and sites where seasonal redistribution of grazing is possible. This result has applied significance for planning pasture rotation, placing watering points, regulating livestock routes and substantiating restoration measures for degraded pastures (Table 5).

Table 5 - Stages of GIS-based calculation of permissible grazing load

Stage	Operation content	Result
1	Definition of the pasture-land mask and exclusion of non-pasture objects	Spatial pasture layer for calculations
2	Extraction of LAI, FAPAR and FCOVER and calculation of dry-mass productivity	Assessment of forage potential
3	Application of the utilization coefficient considering pasture type	Ecologically permissible part of biomass
4	Relating available forage mass to the requirement of one conditional livestock unit	Load standard at the district scale
5	Mapping results and analyzing overload zones	Basis for pasture rotation and management decisions

Reliability, uncertainty and limitations of the approach

The reliability of the obtained results is determined by the quality of three data groups: accuracy of the pasture mask, representativeness of field surveys and correctness of satellite biophysical parameters. An error in any of these components is transferred to the final permissible-load estimate. Therefore, the study used multi-stage control: expert checking of contours, topological cleaning of the geodatabase, cross-checking of field points and comparison of biophysical parameters with ground descriptions.

The main sources of uncertainty are cloudiness and aerosol haze during the active vegetation period, interannual variability of precipitation, differences in phenological phases by elevation belts, spectral similarity of some land-use types and local heterogeneity of grazing pressure. These factors are especially pronounced in arid districts, where the short period of spring grassland development determines a considerable part of annual forage productivity.

To reduce uncertainty, seasonal composites and time series should be used instead of single images. This approach excludes random anomalies of a specific acquisition date and reveals stable spatial differences. If multi-year data are available, deviations from average condition, recurrence of unfavorable signals and zones of chronically low productivity can additionally be calculated.

A limitation of the study is that the permissible-load calculation reflects potential forage capacity but does not replace a complete farm balance. Practical management must additionally consider actual livestock numbers, grazing seasonality, distance to watering points, territory accessibility, legal status of land parcels and availability of alternative feed resources. Nevertheless, the proposed GIS basis is a necessary spatial framework for such a balance.

Practical significance for district-level pasture management

The practical significance of the research lies in the transition from administratively averaged standards to a territorially differentiated pasture-management system. At the district scale, this makes it possible to compare actual load with calculated forage capacity, identify overloaded sites and plan redistribution of livestock among pasture massifs.

For local authorities, the results can be used to refine pasture-rotation schemes, plan restoration of degraded sites, assess pasture sufficiency around settlements and prepare materials for rational land use. For agricultural producers, such maps allow assessment of the risk of forage-base depletion and selection of optimal periods for using specific sites.

The possibility of annual updating of cartographic information is particularly important. Pasture productivity in the southern regions of Kazakhstan strongly depends on weather conditions in a particular year, and therefore static standards quickly become outdated. Remote sensing makes it possible to promptly update information on vegetation condition before or during the grazing season.

The proposed approach can be integrated into regional geoinformation systems for land monitoring. With regular updating of satellite data and field control observations, such a system can perform not only inventory but also forecasting and management functions: identifying degradation-risk zones, assessing recovery after load reduction and supporting decision-making on sustainable use of pasture resources.

Pasture-management zoning based on integrated GIS assessment

Integrated GIS assessment makes it possible to move from the description of separate indicators to functional zoning of pastures. Within such zoning, each site is considered not only as a source of forage mass but also as an element of a landscape system with a particular resistance to grazing. This is fundamentally important for arid territories because sites with the same productivity may have different recovery capacities after grazing pressure.

At the first level, pastures with relatively stable grass cover and sufficient projective cover are identified. These territories can be used within planned pasture rotation if the calculated load is observed. At the second level, sites with limited productivity are identified; for them, permissible load should be adjusted downward, and grazing periods should be linked to the phase of maximum grassland development. At the third level are degraded, saline or highly sparse pastures, where the main management decision should not be increased use but restoration and temporary load reduction.

For district planning, it is important to consider the spatial connectivity of pastures. Even if the overall forage-mass balance for a district is positive, a local deficit around settlements and watering points may persist. In such cases, overloading is formed not by an absolute shortage of pastures but by uneven territorial accessibility. Therefore, permissible-load maps should be analyzed jointly with the road network, watering points, livestock-driving distances and actual livestock distribution (Table 6).

Table 6 - Interpretation classes for district-level pasture management

Class	**Cartographic feature**	**Management interpretation**
Sustainable use	High or medium projective cover, stable LAI/FCOVER	Use within the calculated load standard
Limited use	Low productivity or high seasonal variability	Load reduction, short grazing period, recovery control
Degradation risk	Sparse cover, low FCOVER, salinity or trampling signs	Temporary grazing restriction and restoration measures
Monitoring priority	High parameter heterogeneity and proximity to settlements	Annual remote sensing control and repeated field surveys

Role of field photographs and route maps in interpretation control

The figures used in the article perform not an illustrative but a methodological function. Figure 1 shows a set of interpretation features required to distinguish pastures from cropland, fallow land and hayfields. This is important because in the southern regions of Kazakhstan some fallow lands and dry hayfields are spectrally similar to pastures. Without such comparison, the probability of class mixing and incorrect calculation of pasture area increases.

Figures 4 and 5 reveal the connection between office processing and field control. The route map shows how control points are distributed within the district, and the photograph of the test polygon makes it possible to compare the digital position of a point with the actual condition of grass cover. Such comparison is especially necessary when assessing pastures where the satellite signal may be caused by both vegetation mass and soil background.

Recommendations for improving the monitoring system

To improve the scientific and applied accuracy of monitoring, annual updating of biophysical parameters should be organized in the same phenological periods. A single calendar date is unacceptable for different natural zones of southern Kazakhstan: in flat arid districts, the maximum of grass cover occurs earlier than in foothill and mountain districts. Therefore, the compositing date should be determined by the dynamics of a vegetation index and the actual phase of grassland development.

The network of permanent control polygons should be expanded. Single field surveys describe pasture condition in a specific year; however, repeated productivity is more important for load regulation. Permanent polygons make it possible to assess interannual variability, stability of plant formations and pasture response to decreased or increased grazing.

As an additional direction, it is advisable to use data on relief, soils and accessibility of watering points. Slopes, aspect, soil texture and salinity influence pasture resistance to grazing no less than current green biomass. Integration of these factors will make it possible to create not only a productivity map but also a map of ecologically permissible use.

For practical implementation, the results should be presented as district GIS layers and tabular standards suitable for updating. The optimal structure includes a pasture-contour layer, a layer of biophysical parameters, a productivity layer, a permissible-load layer, an actual-use layer and a priority-measures layer. This structure allows the materials to be used not only in a scientific article but also in land and pasture resource management systems (Table 7).

Table 7 - Recommended components of an operational GIS-based pasture monitoring system

GIS component	Content	Purpose
Pasture mask	Pasture-land contours with administrative linkage	Base layer for all calculations
Remote-sensing parameters	LAI, FAPAR, FCOVER and seasonal composites	Assessment of vegetation condition and dynamics
Field polygons	Coordinates, species composition, projective cover and productivity	Calibration and validation of satellite data
Productivity	Calculation of dry forage mass by polygons or cells	Determination of forage capacity
Permissible load	Use standard considering utilization coefficient	Planning of grazing and pasture rotation
Risk and measures	Zones of overload, degradation and restoration	Support for management decisions

Scientific novelty and applied significance

The scientific novelty of the work lies in the integrated combination of remotely sensed biophysical parameters, geobotanical descriptions and district-level calculation of permissible load. Unlike approaches based only on normative average values, the proposed scheme considers spatial heterogeneity of pastures, differences in vegetation formations and actual ground indicators of grass cover.

The methodological contribution is that remote sensing data are used not only for visualization of vegetation condition but also as a quantitative source for calculating forage capacity. This increases the analytical value of satellite data and enables a transition from overview monitoring to applied pasture-use regulation.

The applied significance is determined by the possibility of using the results at the district level. For agricultural management, the district scale is the most important because it is sufficiently detailed to account for local differences and simultaneously corresponds to the level at which decisions are made on pasture allocation, load regulation and planning of restoration measures.

The obtained materials can serve as a basis for developing regional rules of rational pasture use, refining maximum permissible load, assessing degradation risk and forming a digital archive of pasture-land condition. With regular updating, such data can be used to monitor the consequences of climate change, drought years and anthropogenic pressure on forage resources.

Generalized workflow for reproducing the methodology

To reproduce the methodology in other regions of Kazakhstan, a sequential algorithm is advisable. First, an initial spatial database is formed, including administrative boundaries, land use, satellite images and existing pasture materials. Then a pasture-land mask is created with exclusion of non-pasture objects and mandatory topological checking.

After mask preparation, biophysical parameters are calculated for the period of active vegetation. The resulting rasters are aggregated by pasture polygons or used in a cell-based model. At the next stage, test polygons are selected to cover the main spectral, landscape and vegetation differences of the district. Geobotanical descriptions and productivity measurements are carried out on these polygons.

Then a relationship is built between field data and satellite parameters. After calibration, the model is applied to the entire pasture mask of the district, which makes it possible to obtain the spatial distribution of productivity. At the final stage, productivity is converted into permissible load considering the utilization coefficient and the requirement of one conditional livestock unit.

The advantage of this algorithm is its scalability. It can be applied both to individual districts and to the regional level, provided that a unified database structure and field verification methodology are maintained. This creates prerequisites for the formation of a comparable national system for monitoring pasture resources.

Conclusion

The study confirmed the effectiveness of integrating Earth remote sensing data, GIS analysis and field geobotanical surveys for assessing pasture lands in the southern regions of Kazakhstan. The created digital maps of pasture lands provide a spatial basis for district-level analysis and subsequent grazing regulation.

The largest area of digitized pastures was identified in Kyzylorda Region - 15.14 million ha, followed by Turkestan Region - 9.12 million ha, Zhambyl Region - 8.35 million ha, Zhetysu Region - 8.34 million ha and Almaty Region - 6.32 million ha. However, area alone is not a sufficient criterion of pasture capacity because forage potential is determined by productivity, projective cover, species composition and degree of degradation.

Biophysical parameters LAI, FAPAR and FCOVER revealed spatial differences in vegetation condition. More favorable conditions for grassland formation are typical of Almaty and Zhetysu regions. Turkestan, Zhambyl and Kyzylorda regions have more pronounced limitations associated with aridity, low closure of vegetation cover and heterogeneous productivity.

The calculation of permissible grazing load should consider dry pasture-mass productivity, utilization coefficient and the requirement of one conditional livestock unit. The proposed methodological scheme can be used to develop district-level standards, plan pasture rotation, refine land-use management decisions and prevent degradation of pasture ecosystems.

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ГЕОИНФОРМАЦИОННОЕ КАРТОГРАФИРОВАНИЕ ПАСТБИЩНЫХ УГОДИЙ ЮЖНЫХ РЕГИОНОВ КАЗАХСТАНА НА ОСНОВЕ ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ

Аннотация. В статье представлены результаты геоинформационного картографирования пастбищных угодий южных регионов Казахстана на основе данных дистанционного зондирования Земли, ГИС-анализа и материалов полевых геоботанических обследований. Объектами исследования являлись пастбищные территории Алматинской, Жамбылской, Жетысуской, Кызылординской и Туркестанской областей, различающиеся контрастными природно-климатическими условиями, неоднородным почвенно-растительным покровом, степенью аридности и уровнем антропогенной нагрузки. Актуальность исследования определяется необходимостью формирования объективной цифровой основы для оценки состояния пастбищ, уточнения их пространственного распространения и обоснования допустимой пастбищной нагрузки на районном уровне. В качестве исходных материалов использованы административные границы областей и районов, спутниковые снимки среднего пространственного разрешения, цифровые слои землепользования, результаты визуально-экспертного дешифрирования, а также полевые данные о видовом составе, проективном покрытии, высоте травостоя, продуктивности и кормовой ценности пастбищной растительности. Методика включала формирование пространственной базы данных, выделение пастбищных угодий, исключение непастбищных объектов, расчет биофизических параметров растительности и сопоставление спутниковой информации с материалами полевых обследований. При выборе тестовых полигонов также учитывались различия природных зон, сезонная динамика травостоя и спектральная однородность растительных формаций. На основе ГИС-обработки были созданы цифровые карты пастбищ пяти областей и выполнена оценка показателей LAI, FAPAR и FCOVER, характеризующих развитие листовой биомассы, фотосинтетическую активность и долю поверхности, покрытую зеленой растительностью. Результаты показали выраженную региональную дифференциацию состояния пастбищ: более благоприятные значения биофизических параметров установлены для Алматинской и Жетысуской областей, тогда как пастбища Туркестанской, Жамбылской и Кызылординской областей характеризуются более ограниченным биопродукционным потенциалом. Полевые геоботанические обследования позволили уточнить типы растительных

формаций, провести верификацию результатов дешифрирования и повысить достоверность тематического картографирования. Полученные материалы могут быть использованы для рационального пастбищепользования, пространственного планирования пастбищной нагрузки, разработки районных нормативов и предотвращения деградации пастбищных экосистем южного Казахстана.

Ключевые слова: пастбищные угодья; дистанционное зондирование Земли; ГИС; биофизические параметры; геоботаническое обследование; пастбищная нагрузка; южный Казахстан; LAI; FAPAR; FCOVER; допустимая пастбищная нагрузка.

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ЖЕРДІ ҚАШЫҚТЫҚТАН ЗОНДТАУ ДЕРЕКТЕРІ НЕГІЗІНДЕ ҚАЗАҚСТАННЫҢ ОҢТҮСТІК ӨҢІРЛЕРІНДЕГІ ЖАЙЫЛЫМДЫҚ ЖЕРЛЕРДІ ГЕОАҚПАРАТТЫҚ КАРТОГРАФИЯЛАУ

Аңдатпа. Мақалада Жерді қашықтықтан зондтау деректері, ГАЖ-талдау және далалық геоботаникалық зерттеу материалдары негізінде Қазақстанның оңтүстік өңірлеріндегі жайылымдық жерлерді геоақпараттық картографиялау нәтижелері берілген. Зерттеу нысандары ретінде табиғи-климаттық жағдайлары, топырақ-өсімдік жамылғысы, аридтілік дәрежесі және антропогендік жүктеме деңгейі әртүрлі Алматы, Жамбыл, Жетісу, Қызылорда және Түркістан облыстарының жайылымдық аумақтары қарастырылды. Зерттеудің өзектілігі жайылымдардың жай-күйін бағалау, олардың кеңістіктік таралуын нақтылау және аудандық деңгейде рұқсат етілетін жайылымдық жүктемені негіздеу үшін объективті цифрлық негіз қалыптастыру қажеттілігімен анықталады. Бастапқы материалдар ретінде облыстар мен аудандардың әкімшілік шекаралары, орташа кеңістіктік ажыратымдылықтағы спутниктік суреттер, жер пайдалану бойынша цифрлық қабаттар, визуалды-сараптамалық дешифрлеу нәтижелері, сондай-ақ өсімдіктердің түрлік құрамы, проективтік жамылғысы, шөптесін жамылғының биіктігі, өнімділігі және жайылымдық өсімдіктердің малазықтық құндылығы жөніндегі далалық деректер пайдаланылды. Әдістеме кеңістіктік деректер базасын қалыптастыруды, жайылымдық жерлерді бөліп көрсетуді, жайылымға жатпайтын нысандарды алып тастауды, өсімдіктердің биофизикалық параметрлерін есептеуді және спутниктік ақпаратты далалық зерттеу материалдарымен салыстыруды қамтыды. Тестілік полигондарды таңдау кезінде табиғи зоналардағы айырмашылықтар, шөптесін жамылғының маусымдық динамикасы және өсімдік формацияларының спектрлік біртектілігі де ескерілді. ГАЖ-өңдеу негізінде бес облыс бойынша жайылымдардың цифрлық карталары жасалып, жапырақ биомассасының дамуын, фотосинтетикалық белсенділікті және жер бетінің жасыл өсімдікпен жабылу үлесін сипаттайтын LAI, FAPAR және FCOVER көрсеткіштері бағаланды. Нәтижелер жайылымдардың жағдайында айқын өңірлік дифференциация бар екенін көрсетті: биофизикалық параметрлердің неғұрлым қолайлы мәндері Алматы және Жетісу облыстарында анықталса, Түркістан, Жамбыл және Қызылорда облыстарының жайылымдары биопродукциялық әлеуетінің салыстырмалы түрде шектеулі болуымен сипатталды. Далалық геоботаникалық зерттеулер өсімдік формацияларының типтерін нақтылауға, дешифрлеу нәтижелерін верификациялауға және тақырыптық картографиялаудың сенімділігін арттыруға мүмкіндік берді. Алынған материалдар жайылымдарды ұтымды пайдалану, жайылымдық жүктемені кеңістіктік жоспарлау, аудандық нормативтерді әзірлеу және Қазақстанның оңтүстігіндегі жайылымдық экожүйелердің деградациясын болдырмау үшін қолданылуы мүмкін.

Кілт сөздер: жайылымдық жерлер; Жерді қашықтықтан зондтау; ГАЖ; биофизикалық параметрлер; геоботаникалық зерттеу; жайылымдық жүктеме; оңтүстік Қазақстан; LAI; FAPAR; FCOVER; рұқсат етілетін жайылымдық жүктеме.