Keywords: socio-economic dynamics, land use, agriculture, research methods, Kazakhstan, sustainable development, resource optimization, GIS, food security.

Вклад авторов. Д. Курданов принимал активное участие в концептуализации исследования, занимался сбором и курированием данных, проводил формальный анализ и статистические расчёты. Также он подготовил первичный черновик рукописи, участвовал в проверке данных и оформлении визуальных материалов, а также принимал участие в редактировании текста. Г. Айтхожаева выступила научным руководителем проекта, обеспечила руководство и контроль всех этапов работы. Она занималась концептуализацией исследования, разработкой методологии и общей методологической базы, контролировала качество данных и верификацию результатов. Г. Айтхожаева также обеспечила приобретение финансирования и необходимые ресурсы, руководила администрированием проекта, осуществляла координацию написания статьи и выступала главным редактором рукописи. Н.Турманбетов внес вклад в концептуализацию, участвовал в сборе и предварительной обработке данных, а также в проведении расследования и полевых исследований. Он помогал в разработке методологии, анализа данных, участвовал в проверке и корректуре текста, а также в подготовке визуальных материалов и редактировании статьи.

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ASSESSING LAND SUITABILITY FOR IRRIGATED AGRICULTURE IN THE NORTH KAZAKHSTAN REGION USING MULTI-CRITERIA DECISION ANALYSIS

Abstract

This article presents an approach to assessing land suitability for irrigated agriculture based on the Multi-Criteria Decision Analysis (MCDA) method using weighted summation. The aim of the study is to integrate various factors affecting the potential of land for irrigation, taking into account their relative importance. The study is focused on the development and testing of a methodology for evaluating the degree of land suitability for irrigated agriculture in the North Kazakhstan Region of the Republic of Kazakhstan. Ten key criteria were identified and quantitatively assessed, including soil, geological parameters, land use, and others. The Analytic Hierarchy Process (AHP) method was used to determine the weights of the criteria, which made it possible to structure complex decisions based on pairwise comparisons of criteria. The calculation results, presented in the form of a spatial differentiation map, showed zones with different degrees of suitability for irrigated agriculture. The analysis showed that a high degree of suitability is mainly observed in the northwestern part of the region near lakes and along the Ishim River, whereas lands with low suitability prevail in the southern and southeastern parts. The developed methodology makes it possible not only to determine the current potential of land resources but also to take into account factors affecting their sustainability in the long term. This provides a basis for informed decision-making in the field of sustainable agricultural development and planning, as well as for identifying promising areas for the development of irrigated systems.

Key words: *irrigated agriculture, land suitability, multi-criteria decision analysis, weighted sum, North Kazakhstan Region, agroecosystem sustainability*

Introduction

The problem of ensuring food security in the context of global climate change requires a revision and optimization of approaches to land resource use, particularly for areas located in vulnerable agro-climatic zones—moderately humid moderately warm, slightly humid moderately warm, and slightly arid moderately warm—of the North Kazakhstan Region [1]. The majority of agricultural production in the region is concentrated on rain-fed crops [2]. Irrigated agriculture plays a key role in increasing the productivity of agricultural lands [3]; however, its mismanagement can lead to soil degradation [4], secondary salinization [5], and depletion of water resources [6, 7]. Globally, irrigated agriculture occupies about 17% of all cultivated land but produces approximately 41% of crop output; in Kazakhstan, irrigated lands represent only 6.5% of total arable land, yet they account for roughly 40% of national crop production, underscoring the strategic importance of water management for agricultural development [8].

In this context, research on comprehensive land-suitability assessment for irrigation is increasingly relevant, as it allows for minimizing risks and enhancing the resilience of agroecosystems. Hadelan et al. (2020) identified criteria and developed assessment models using multi-criteria decision-making methods to compare pre-defined sites for irrigation-system construction [9]. Bozdağ et al. (2016) applied multi-criteria analysis in conjunction with GIS techniques to determine the degree of land suitability over a specific area [10]. Paul et al. (2020) integrated geospatial multi-criteria decision analysis with the Analytic Hierarchy Process (AHP) to evaluate the potential for using treated water for agricultural irrigation in California [11]. Similarly, Rihab et al. (2024) demonstrated that selecting an MCDA method for classifying areas suitable for irrigation with treated water depends on several factors, including decision complexity, data availability, decision-makers' preferences, and available computational resources [12].

The present study aims to develop and test a methodology for assessing land suitability for irrigated agriculture in the North Kazakhstan Region of the Republic of Kazakhstan, based on Multi-Criteria Decision Analysis (MCDA) and the Analytic Hierarchy Process (AHP), using the Weighted Sum tool within the ArcGIS Pro environment [13, 14, 15, 16, 17]. The methodology integrates publicly available datasets relevant to sustainable irrigation analysis and planning.

The main scientific contribution lies in establishing a transparent, data-driven, and reproducible workflow for irrigation suitability assessment in a region where such systematic approaches have not been operationalized. Unlike prior studies that rely primarily on static soil or land-use factors, this study explicitly incorporates snowpack-derived water supply potential, surface-runoff pathways, and slope-controlled retention capacity, thereby linking irrigated agriculture planning with the hydrologic reality of snowmelt-driven water availability in Northern Kazakhstan. The analytic procedure ensures replicability by using open-source climate and elevation products, consistent spatial pre-processing, AHP-derived weights validated through consistency checks, and clear parameter ranges for each suitability factor.

The novelty of this research stems from applying a standardized MCDA-AHP framework for irrigation planning in Kazakhstan's northern steppe, systematically integrating snow water equivalent (SWE), slope-derived runoff accumulation, and soil moisture-retention indicators into the suitability criteria, reflecting the importance of seasonal meltwater resources, and demonstrating that robust and reproducible irrigation-suitability mapping can be achieved using openly available data and a fully documented decision-weighting scheme.

It is assumed that key natural, agroecological, and hydrological criteria significantly influence land suitability for irrigation and that these can be quantitatively assessed and normalized to ensure comparability. Furthermore, the study posits that heterogeneous factors can be integrated into a single suitability index using a weighted-summation approach in a GIS framework [13].

The practical significance of the findings lies in providing an evidence-based tool to support decision-making for irrigation planning and management. The resulting suitability map can guide the identification of areas most promising for irrigation-system development and highlight zones requiring reclamation or land-use modification, contributing to more efficient and sustainable use of agricultural lands amid rising food demand and a changing climate.

Study Area

The study area (Figure 1) is the North Kazakhstan Region, located in the northern part of the Republic of Kazakhstan. The region covers an area of 123,200 km² and shares a border with the Russian Federation. The climate is sharply continental, with significant annual temperature fluctuations and low humidity levels. The territory lies mainly within the West Siberian Plain and is characterized by numerous closed depressions with lake clusters and isolated water bodies.

Precipitation is unevenly distributed: the average annual amount ranges from 225 to 335 mm, with recorded extremes from 204 mm to over 600 mm. The coldest month is January (average temperature −18.5 to −18.7 °C), and the warmest is July (+18.5 to +18.7 °C). In winter, precipitation varies from 22 to 42 mm, and snow cover is unevenly distributed due to strong winds that shift snow across open areas.

The soil cover follows a zonal distribution: in the north, ordinary loamy chernozems dominate, while in the south, lighter-textured southern chernozems prevail.

Figure 1. Map of the study area

Data and Methods

To assess the degree of land suitability for irrigated agriculture, this study employed the Multi-Criteria Decision Analysis (MCDA) method, integrating the Weighted Sum approach with the Analytic Hierarchy Process (AHP) [16, 18]. The traditional AHP method was selected because of its robust theoretical foundation, its capacity to address complex decision-making problems through hierarchical structuring, and its independence from large, authentic datasets [19].

The methodological framework comprised several key stages. First, ten relevant criteria influencing land suitability for irrigated agriculture were identified using publicly available datasets. These criteria included: (1) soil type, representing various soil classes such as chernozems, chestnut soils, and sierozems [20]; (2) soil organic carbon sequestration rate (Figure 2), which indicates the soil's capacity for long-term sustainable functioning and humus accumulation [21]; (3) land productivity dynamics, expressed through a map illustrating productivity changes between 2001 and 2022 and categorizing territories according to degradation or improvement levels [21]; (4) soil salinity [21]; (5) geology, described by geological mapping that delineates the spatial distribution of rock types, their ages, and structural characteristics [22]; (6) subsurface flow, which characterizes the distribution of aquifer complexes and horizons within sedimentary strata [23]; (7) groundwater, focusing on aquifers closest to the surface [24]; (8) distance to water bodies, calculated by the authors; (9) slope, derived from the Shuttle Radar Topography Mission (SRTM) 30-m digital elevation model [25]; and (10) land use, depicted in Figure 3, showing the spatial distribution of different land-cover categories, including agricultural areas, forests, pastures, water bodies, urban zones, and uninhabited lands [26].

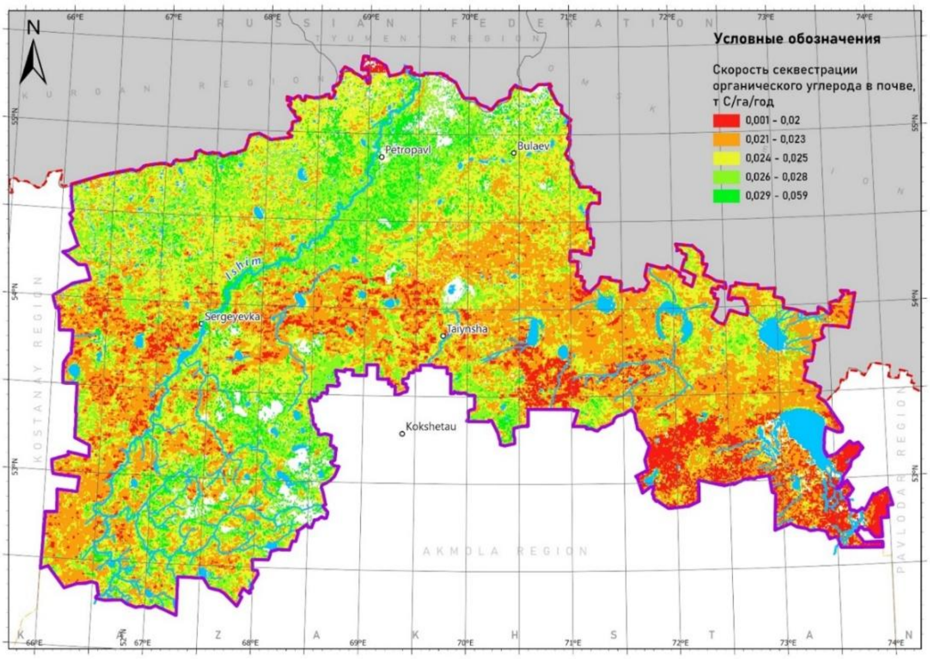

Figure 2. Map of the rate of soil organic carbon sequestration in the North Kazakhstan region

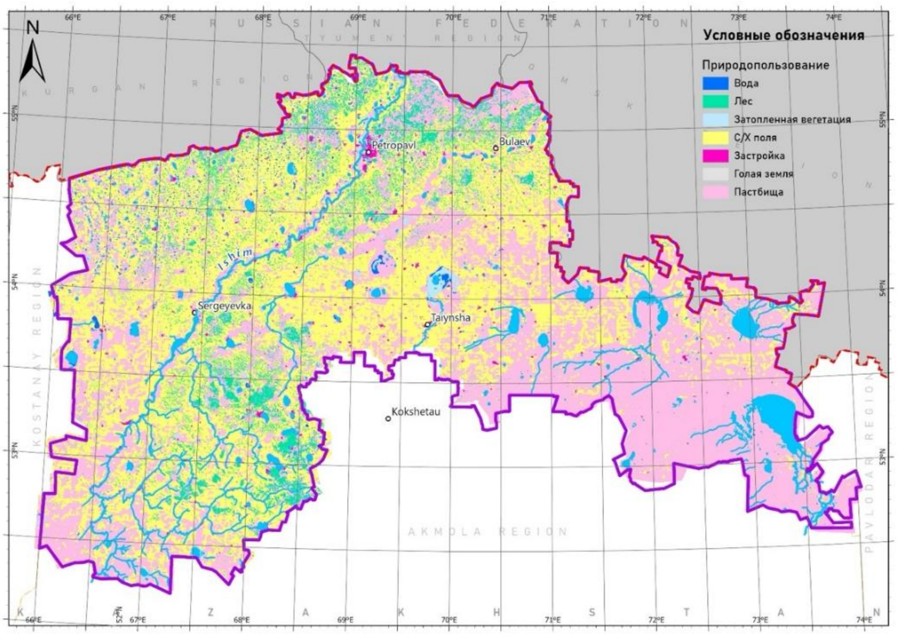

Figure 3. Land use/Land Cover (LULC) map of the North Kazakhstan region
Source: ESRI LULC, compiled by authors

Each criterion was quantitatively evaluated and normalized to ensure comparability. All ten input raster layers were reclassified into suitability scores prior to weighting. For continuous variables such as soil organic carbon sequestration rate, soil salinity, and other continuous biophysical parameters, reclassification was performed using their value distributions, dividing the range into four equal-interval suitability classes (25% intervals). This approach ensures that the full spectrum of variation for each criterion is captured and enables a consistent suitability ranking across heterogeneous datasets.

Categorical data, such as LULC, were reclassified based on literature-supported suitability rankings for irrigated agriculture. For example, water bodies and built-up areas were assigned the lowest suitability value (1), flooded vegetation was assigned 3, bare ground 5, forest 4, pastureland 8, and cropland the highest value of 10, reflecting its inherently higher suitability for irrigation development in the study context.

The weighting of criteria was performed using the AHP, which structures complex decisions through pairwise comparison matrices. Pairwise comparisons of the selected criteria (Figure 4) were conducted by the authors using the Saaty 1–9 scale [15] to quantify the relative importance of each factor. In total, 45 comparisons were completed using an online AHP decision-support tool [17], and the consistency ratio was evaluated to ensure coherence and reliability in the weighting results.

	1	2	3	4	5	6	7	8	9	10
1	1	3.00	4.00	2.00	1.00	4.00	3.00	2.00	2.00	1.00
2	0.33	1	2.00	0.50	0.25	2.00	1.00	0.33	0.33	0.25
3	0.25	0.50	1	0.50	0.33	0.50	1.00	0.33	0.50	0.25
4	0.50	2.00	2.00	1	2.00	2.00	2.00	1.00	0.50	0.50
5	1.00	4.00	3.00	0.50	1	3.00	2.00	1.00	2.00	1.00
6	0.25	0.50	2.00	0.50	0.33	1	0.50	0.50	0.50	3.00
7	0.33	1.00	1.00	0.50	0.50	2.00	1	0.50	0.50	0.33
8	0.50	3.00	3.00	1.00	1.00	2.00	2.00	1	2.00	0.50
9	0.50	3.00	2.00	2.00	0.50	2.00	2.00	0.50	1	0.50
10	1.00	4.00	4.00	2.00	1.00	0.33	3.00	2.00	2.00	1

Figure 4. Pairwise comparison matrix of the criteria. The numbers from 1 to 10 correspond to the numbering of the criteria in the "Criteria Definition" section

Based on the pairwise comparison matrix, the normalized weights of the criteria were derived using the eigenvector method. To assess the logical consistency of expert judgments, the Consistency Ratio (CR) was calculated. The resulting CR value was 8.6%, which falls within the acceptable threshold of less than 10% [14]. The computed weights of the criteria varied according to their relative importance (Table 1).

Table 1. Criteria and their weights

Criterion	Weight
Soil	0.170
Soil organic carbon sequestration rate	0.054
Land productivity dynamics	0.038
Soil salinity	0.104
Geology	0.135
Subsurface flow – Distribution of aquifer complexes and horizons in deposits	0.081
Groundwater – Aquifers lying closest to the surface	0.058
Distance to water bodies	0.113
Slope	0.099
Land use	0.148

For each spatial unit (e.g., land parcel or raster pixel), a weighted sum was computed using the Weighted Sum tool available in the ArcGIS Pro software package [13]. In this process, the value of each criterion was multiplied by its corresponding weight, and the resulting products were summed to obtain the overall suitability score. The calculation followed the formula:

$$s_i = \sum_{j=1}^{n}(w_j \times x_{ij}) \qquad (1)$$

where s_i is the final suitability score for unit i, w_j is the weight of criterion j, x_{ij} is the normalized value of criterion j for unit i, n is the total number of criteria.

The obtained s_i values were used to classify land into five suitability categories, ranging from low to high. To improve the reliability of the results, iterative checks and sensitivity analysis were conducted to assess the impact of weight changes on the final classification. From an applied perspective, this workflow allows decision-makers and agricultural planners to objectively identify priority zones for irrigation infrastructure, water harvesting systems, and land-reclamation programs. The resulting suitability surface can support regional development strategies, farmer advisory services, and investment planning by highlighting areas where irrigation expansion is likely to be technically feasible, economically viable, and environmentally sustainable.

Results

The conducted analysis revealed clear spatial differentiation in land suitability for irrigated agriculture across the North Kazakhstan Region. The suitability levels were categorized into five classes: low, below average, average, above average, and high. The resulting raster output, visualized on a map (Figure 5), provides a comprehensive overview of the region's spatial variation in irrigation potential.

The land suitability map for irrigated agriculture (Figure 5) shows a clear northwest–southeast gradient driven by interacting geologic–pedologic, hydrologic–climatic, and anthropogenic controls.

Higher suitability areas (light and dark green) coincide with the Esil River valley and adjacent lowlands (e.g., Sergeevka–Bulaevo corridor), underlain by Quaternary alluvial and loess-like deposits that weather to medium- to fine-textured chernozem soils with good water-holding capacity and moderate infiltration. Drainage density and runoff accumulation are higher along the Ishim and its tributaries, and proximity to existing reservoirs and floodplains increases seasonal water availability from snowmelt-fed flows. Slopes are generally <3–5%, reducing erosion risk and pumping head, and the groundwater table is comparatively shallower in valley bottoms, which can lower conveyance costs. Land use is dominated by cropland and pasture, which our LULC reclassification assigns higher suitability scores. Built-up and protected areas are sparse. Together, these factors produce consistently higher composite suitability indices.

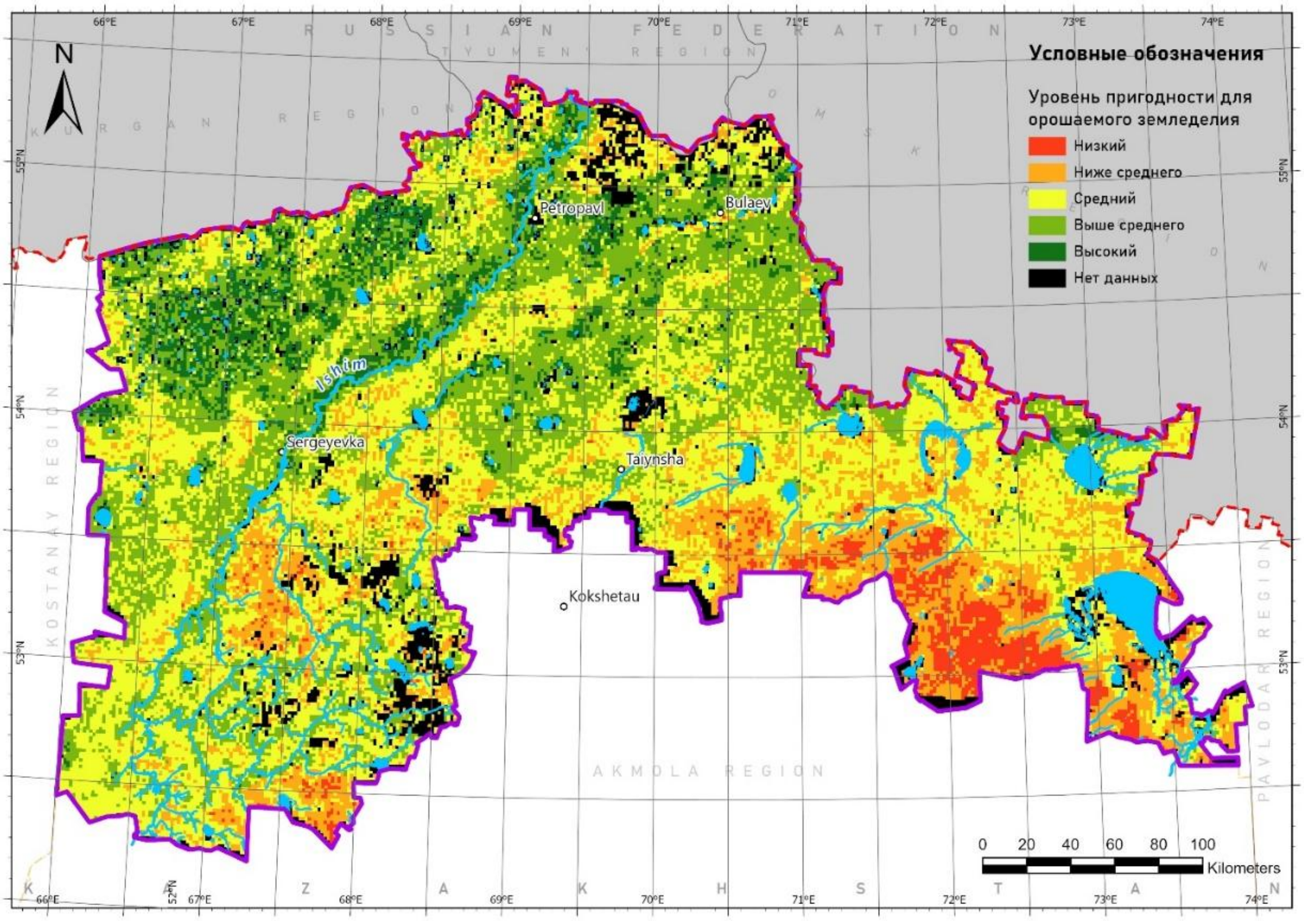

Figure 5. Land suitability map for irrigated agriculture of North Kazakhstan region

Toward the Pavlodar and Akmola borders on the southeast (orange and red colors), the landscape transitions to more saline lacustrine and alluvial–proluvial deposits with a higher frequency of solonetz/solonchak complexes. Our continuous rasters (e.g., soil salinity) therefore down-rank these zones. The climate signal strengthens southeastward: precipitation declines and PET increases, reducing reliable surface-water surpluses from snowmelt and raising irrigation requirements. Topographically, the dissected periphery of the Kokshetau Uplands introduces steeper local slopes, elevating erosion hazard and infrastructure costs. Hydrologically, runoff convergence and perennial channels are less dense, and many basins terminate in closed saline depressions rather than passable conveyance routes. Anthropogenic constraints also accumulate: fragmented cropland, more bare/abandoned patches, and scattered settlements (all reclassified to lower suitability classes) interrupt contiguous service areas for canals or pipelines. These combined factors depress the weighted scores and explain the concentration of "below-average" and "low" classes in the south and southeast.

Overall, high-suitability zones align with alluvial lowlands, gentle relief, chernozem-dominated soils, and snowmelt-supported hydrology, whereas low-suitability zones reflect saline substrates, higher PET/deficit, steeper or dissected terrain, weaker channel networks, and less favorable LULC. This process-based reading confirms that the mapped pattern is consistent with the region's geology, hydrology, and land use.

Conclusions

This study presents a structured and reproducible approach to evaluating land suitability for irrigated agriculture in the North Kazakhstan Region using Multi-Criteria Decision Analysis (MCDA) and the AHP. By integrating ten critical criteria, including soil characteristics, geological features, hydrological factors, topography, and land use, the methodology provides a comprehensive framework for spatially assessing irrigation potential across a heterogeneous landscape.

The resulting land suitability map reveals significant spatial variation in irrigation potential, with the most favorable areas located in the northwestern part of the region, particularly along the Ishim River and near lake systems. These zones benefit from advantageous soil conditions, access to water resources, and gentle terrain. In contrast, the southern and southeastern parts of the region are characterized by lower suitability, likely due to a combination of soil salinity, steeper slopes, and limited water accessibility.

The use of the AHP method enabled the systematic weighting of criteria based on expert judgment, ensuring that the resulting suitability index reflects the relative importance of each factor. The consistency ratio of the pairwise comparison matrix remained within acceptable limits, supporting the reliability of the weight assignments.

The developed methodology serves as a valuable decision-support tool for policymakers, land managers, and agricultural planners. It not only helps identify priority areas for the expansion of irrigation systems but also highlights regions where additional land reclamation or resource management interventions may be required. Furthermore, the approach offers flexibility for adaptation to other regions and contexts, provided that relevant spatial data are available.

In the context of increasing pressures on food systems and climate variability, this study contributes to the broader goal of promoting sustainable agricultural development. The integration of environmental, agroecological, and infrastructural criteria into a unified assessment framework facilitates informed decision-making and supports long-term land and water resource planning in vulnerable agroecosystems.

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СОЛТҮСТІК ҚАЗАҚСТАН ОБЛЫСЫНДА СУАРМАЛЫ ЕГІНШІЛІККЕ ЖЕРЛЕРДІҢ ЖАРАМДЫЛЫҒЫН КӨП КРИТЕРИЙЛІК ШЕШІМ ҚАБЫЛДАУ ӘДІСІ АРҚЫЛЫ БАҒАЛАУ

Аңдатпа

Бұл мақалада салмақталған қосынды әдісін қолданатын көп критерийлік шешім қабылдау (MCDA) әдісіне негізделген суармалы егіншілікке арналған жерлердің жарамдылығын бағалау тәсілі ұсынылады. Зерттеудің мақсаты – суармалы егіншілікке жердің әлеуетіне әсер ететін әртүрлі факторларды олардың салыстырмалы маңыздылығын ескере отырып біріктіру. Зерттеу Солтүстік Қазақстан облысының аумағында суармалы егіншілікке арналған жерлердің жарамдылық дәрежесін бағалауға арналған әдістемені әзірлеуге және сынақтан өткізуге бағытталған. Топырақ, геологиялық параметрлер, жерді пайдалану және басқа да он негізгі критерий анықталып, сандық тұрғыдан бағаланды. Критерийлердің салмақтарын анықтау үшін иерархиялар анализі (AHP) әдісі қолданылды, бұл критерийлердің жұптық салыстыруларына негізделген күрделі шешімдерді құрылымдауға мүмкіндік берді. Есептеу нәтижелері кеңістіктік дифференциация картасы түрінде ұсынылды және суармалы егіншілікке жарамдылықтың әртүрлі дәрежелері көрсетілді. Талдау көрсеткендей, жоғары жарамдылық аймақтары негізінен аймақтың солтүстік-батысында, көлдер мен Есіл өзенінің бойында орналасқан, ал төмен жарамдылықтағы жерлер оңтүстік және оңтүстік-шығыс бөліктерде басым. Дайындалған әдістеме жер ресурстарының қазіргі әлеуетін анықтап қана қоймай, олардың ұзақ мерзімді тұрақтылығына әсер ететін факторларды да ескеруге мүмкіндік береді. Бұл ауыл шаруашылығын тұрақты дамыту мен жоспарлау саласында негізделген шешімдер қабылдауға, сондай-ақ суармалы жүйелерді дамытуға перспективалы аумақтарды анықтауға негіз болады.

Кілт сөздер: суармалы егіншілік, жер жарамдылығы, көп критерийлі шешім қабылдау, салмақталған қосынды, Солтүстік Қазақстан облысы, агроэкожүйелердің тұрақтылығы

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ОЦЕНКА ПРИГОДНОСТИ ЗЕМЕЛЬ ДЛЯ ОРОШАЕМОГО ЗЕМЛЕДЕЛИЯ В СЕВЕРО-КАЗАХСТАНСКОЙ ОБЛАСТИ С ИСПОЛЬЗОВАНИЕМ МЕТОДА МНОГОКРИТЕРИАЛЬНОГО АНАЛИЗА

Аннотация

В статье представлен подход к оценке пригодности земель для орошаемого земледелия на основе метода многокритериального анализа (МКА), использующего взвешенное суммирование. Цель исследования заключается в интеграции различных факторов, влияющих на потенциал земель для орошения, с учётом их относительной значимости. Исследование направлено на разработку и апробацию методики оценки степени пригодности земель для орошаемого земледелия в Северо-Казахстанской области Республики Казахстан. Были выделены и количественно оценены десять ключевых критериев, включая почву, геологические параметры, землепользование и другие. Метод анализа иерархий (AHP) использовался для определения весов критериев, что позволило структурировать сложные решения на основе попарного сравнения. Результаты расчетов, представленные в виде карты пространственной дифференциации, показали зоны с различной степенью пригодности для орошаемого земледелия. Анализ показал, что высокая степень пригодности в основном наблюдается в северо-западной части региона, вблизи озёр и вдоль реки Ишим, тогда как земли с низкой пригодностью преобладают в южной и юго-восточной части. Разработанная методика позволяет не только определить текущий потенциал земельных ресурсов, но и учитывать факторы, влияющие на их устойчивость в долгосрочной перспективе. Это создает основу для обоснованного принятия решений в области устойчивого сельскохозяйственного развития и планирования, а также для выявления перспективных территорий для развития систем орошения.

Ключевые слова: орошаемое земледелие, пригодность земель, многокритериальный анализ, взвешенная сумма, Северо-Казахстанская область, устойчивость агроэкосистем

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«ҚҰЛАННЫҢ (EQUUS HEMIONUS) РЕИНТРОДУКЦИЯСЫН ІЛЕ-БАЛҚАШ МЕМЛЕКЕТТІК ТАБИҒИ РЕЗЕРВАТЫНЫҢ ІЛЕ ӨЗЕНІНІҢ САҒАЛЫҚ ЭКОЖҮЙЕСІ ЖАҒДАЙЫНДА ЖҮЗЕГЕ АСЫРУ»

Аңдатпа

Бұл мақалада құланның (Equus hemionus) «Іле-Балқаш» МТР-ты аумағына реинтродукциясы кезінде олардың жаңа экожүйелерге бейімделуі мен биологиялық негіздемесі қарастырылады. Жануардың биологиялық ерекшелігі, таралу ареалы, дене бітімі, салмағы, төлдеу және көбею кезіндегі мінез-құлқы қарастырылған. Құландардың мекен ету аймағының табиғи-климаттық жағдайлары, жақын орналасқан гидрометеорологиялық станциялар деректері, геологиялық құрылымы, рельефі, климаты, гидрологиялық режимі, топырақ жамылғысы мен өсімдіктер дүниесі жан-жақты талданған. Жануарларды арнайы бақылау алаңдарында және волерлерде қадағалау әдістері қарастырылған. Сонымен қатар жерсіндіру кезеңінде құландардың қосымша коректік және минералдық заттармен қамтамасыз ету және олардың коректену кезіндегі мінез-құлқының ерекшеліктеріне тоқталған.